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DETAIL STRATIGRAPHY OF THE BIWABIK IRON-BEARING FORMATION, EAST MESABI DISTRICT, MINNESOTA.[1]

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INTRODUCTION.

In the various iron ranges of the Lake Superior district the location of new ore bodies is in practically all cases a matter of diamond drilling on the basis of most careful geological study. The ore bodies are parts of sedimentary iron-bearing formations where ground waters have caused a local enrichment of iron oxides, thought to be effected chiefly by solution and removal of the associated silica. On the Mesabi iron range of Minnesota, not only is the location of the ore bodies confined to the Biwabik iron-bearing formation, but the different types and qualities of ore are fairly definitely related to differences in the several horizons of the iron formation from which they are derived. Obviously it is extremely desirable that the explorer know at all times in what part of the iron formation he is working, in order that the search for ore bodies be most intelligently directed. A knowledge of the detailed stratigraphy is therefore important.

In 1916 active interest was awakened in the low grade magnetic ores of the eastern end of the Mesabi range. This led to

[1] Published by permission of W. H. Emmons, director, Minnesota Geological and Natural History Survey. To accompany the following article by Frank F. Grout.

drilling operations on rather a large scale. The willingness of the explorers[2] to coöperate by allowing the members of the Minnesota Geological and Natural History Survey to examine the drill cores and records during the progress of the work, led to the detailed mapping of the iron formation from the town of Mesaba eastward to Birch Lake, a distance of eighteen miles. The results are being published in Bulletin 17 of the State Survey.

The Eastern Mesabi is by far the most favorable area on the range for a study of the stratigraphy of the iron formation. Outcrops are numerous, the various horizon markers in many places showing almost continuously in ridges parallel to the strike for half a mile or more. The character of the rock itself in this part of the range favors detailed study. The iron formation in large part was probably originally a chemical precipitate consisting of various combinations of ferruginous chert, ferrous silicate and perhaps some carbonate. On the eastern Mesabi, regional and contact metamorphism has altered it to a medium to coarse-grained intergrowth of magnetite, quartz and amphibole, with other subordinate minerals. Hematite bodies are small and unimportant. No conspicuous secondary structures have developed, with the exception of small drag folds in certain horizons. Premetamorphic features, such as bedding, conglomerate pebbles, organic structures and septaria cracks, are well preserved, even accentuated by the metamorphism. This quartz amphibole magnetite rock is very resistant to weathering processes. On the other hand, weathering over the central and western parts of the range has had the tendency to obscure original differences in the various horizons. Finally, the great assistance in the geological work rendered by the people conducting exploration by placing at our disposal drill cores and records, made the accurate mapping of the horizon boundaries and the determination of their thicknesses a comparatively easy matter.

It is intended here to take up merely the characteristics of the various parts of the Biwabik formation as it exists in the eastern Mesabi, particularly those characteristics which were of most

[2] Swart, W. G., Duluth, Minn., in charge for Hayden Stone & Co.

value in determining the horizons. Many features of the several beds remain constant over the entire area covered. Others are of local importance only. It is hoped that as the study of the Biwabik formation on the main Mesabi range proceeds, those features which were of most use as horizon markers on the east Mesabi will be found to persist for some distance westward from the limit of the present study, at the town of Mesaba.

The importance of being able to recognize with a fair degree of certainty the various horizons of the iron formation has been emphasized by Wolff in his work on the hematite ores of the Mesabi range.[3] In summary it is found that the character of the hematite ore, whether "blue" and "hard" or "brownish yellow" and "soft," is largely determined by the original horizon.

THE DETAILED STRATIGRAPHY OF THE BIWABIK FORMATION.

The stratigraphic succession in the eastern part of the Mesabi district is as follows:

Quaternary system.
  Pleistocene series—Glacial drift.
Unconformity.
Algonkian system.
  Keweenawan series—Duluth gabbro and associated diabase sills and dikes.
  Unconformity.
  Huronian series.

Upper Huronian	Virginia slate. Biwabik formation (iron-bearing). Pokegama quartzite.

  Unconformity.

Lower-Middle Huronian	Giants Range granite. Slate-graywacke-conglomerate formation.

The structure of the upper Huronian sediments on the east Mesabi is simple. The beds rest unconformably upon the eroded

[3] Wolff, J. F., "Recent Geologic Developments on the Mesabi Iron Range, Minnesota," *Trans. Am. Inst. Min. Eng.*, vol. 56, p. 142, 1916.

lower Huronian slates and granite. They strike about N. 50° E., and dip southward at a low angle of 4 to 8 degrees. The thickness of the Biwabik iron formation varies, averaging about 400 feet in the area studied. It is truncated by the Duluth gabbro at the extreme east end of the range.

In the following tabulation of the horizons recognized on the east Mesabi, Wolff's general division of the Biwabik formation into upper and lower slaty and upper and lower cherty beds has been retained.

TABULAR SECTION OF BIWABIK IRON-BEARING FORMATION ON THE EAST MESABI.

Top—Virginia Slate.

Biwabik Iron-bearing Formation.

UPPER SLATY BEDS.	Thickness.
No. 4—Limestone with silicates. Practically no magnetite..	5– 10 feet.
No. 3—Banded amphibole and white quartz; variable amount of calcite. Less than 5 per cent. magnetite	40– 50 feet.
No. 2—Thin bedded iron formation, quartz, amphibole and magnetite in layers averaging less than one eighth inch in thickness. Magnetite increasing toward bottom to about 30 per cent., in places	25– 35 feet.
No. 1—Like No. 2, but with gray lenticular quartzite beds or concretions in which occur numerous white quartz septaria. Between these quartzite beds, the thin beds are drag folded and brecciated. Scattered garnet occurs near the bottom. About 30 per cent. magnetite	40– 45 feet.

UPPER CHERTY BEDS.	Thickness.
No. 4—Highly ferruginous conglomerate. Pebbles of magnetite and hematite in a matrix of quartz and iron oxides. Layers up to several inches in thickness almost pure magnetite. About 40 per cent. magnetite	10 feet.
No. 3—Jasper and recrystallized chert with algal structure and conglomerate. About 20 per cent. magnetite	1– 10 feet.
No. 2—Like No. 4. About 40 per cent. magnetite	20–30 feet.
No. 1—Greenish gray quartz amphibole magnetite rock with conglomerate and granule texture. Many lenticular seams of magnetite. From 25–40 per cent. magnetite over considerable areas	80–110 feet.

LOWER SLATY BEDS.	
No. 2—Fine massive to slaty quartz amphibolite. Few thin magnetite beds. Fayalite crystals in places. About 10–15 per cent. magnetite	65 feet.
No. 1—Black thin bedded fissile slate. About 5 per cent. magnetite	25 feet.
LOWER CHERTY BEDS.	
No. 3—White to gray recrystallized chert with algal structure. In places highly ferruginous, with magnetite and hematite pebbles	10– 15 feet.
No. 2—Beds of variable character, cherts, breccias, clastic sands, dense magnetite ore, etc. Containing 50 per cent. magnetite over considerables areas	2– 52 feet.
No. 1—Basal beds—conglomerates and green shale commonest phases. Less than 5 per cent. magnetite	0– 15 feet.
	350–470 feet.

Bottom—Giant's Range Granite; or Lower-Middle Huronian slate; or Pokegama quartzite.

LOWER CHERTY BEDS.

Bed No. 1 is the base of the Biwabik formation. It is for the most part a conglomerate of variable thickness which fills in many of the irregularities in the Lower Huronian erosion surface. Many of the boulders are of the immediately underlying rock, especially where it is granite. Between the pebbles and in thin layers overlying them are greenish shaly beds. In most places the contact of the upper and lower Huronian is shown by outcrops of the lower Huronian with a thin plaster of the green shale, or of conglomerate pebbles.

Bed No. 2 is the lowest of the magnetite beds. While considerable variation in the types of rock in this horizon was noted, it increases in thickness and iron content from the eastern end, where it is entirely missing or but a few feet in thickness, to Mesaba, where it is over 50 feet thick. The various phases of rock encountered in this horizon include magnetite conglomerates and breccias, and thick beds consisting of magnetite, with calcite, amphibole and clastic quartz. The horizon is of interest in that it is undoubtedly one of the beds in which processes of concentration have produced high grade hematite ore farther west. It is noteworthy that the two small hematite mines east

of Mesaba (which have produced but a few hundred thousand tons of ore in the past), lie in this horizon. While there might be some question as to the identity of the horizon in an isolated outcrop, because of a resemblance to some of the overlying beds, in all cases it could be assigned to its proper place by the character of the neighboring outcrops.

Bed No. 3 outcrops in many places. It was recognized at the extreme end of the iron formation, near Birch Lake and at the western end of the area mapped, in Mesaba. It is a hard recrystallized chert, of fine grain, and is one of two horizons having a peculiar structure ascribed to organic growth. (See description of Bed No. 3 of the Upper Cherty Beds.) The outcrops of the cross sections of these beds show a more or less regular wavy structure such as would be produced by piles of shallow inverted basins 2 to 24 inches in diameter. This structure is emphasized by differential weathering, and color differences of the various layers. In most cases the colors of the parallel basin-shaped layers alternate in grays and whites. In other outcrops, the alternation is white and red of various shades. In the latter case there are many magnetite and hematite pebbles included in the rock. The thickness of these beds is about 15 feet and is fairly constant in the eastern area. Similar forms occur in the iron formations near Hudson's Bay,[4] in the Belt Series of Montana,[5] and in siliceous limestones in the Grand Canyon, Arizona, all of pre-Cambrian age. In these cases the structures are referred to algal growth.

LOWER SLATY BEDS.

Bed No. 1, the bottom of the Lower Slaty Beds, is the most slaty in structure of any part of the iron formation. It is very constant in thickness and character throughout the entire range, and is known as the "intermediate slate." It is thin-bedded and on weathering breaks into thin slabs parallel to the bedding

[4] Moore, E. S., "The Iron Formation on Belcher Islands," *Jour. Geology*, vol. 26, 1918, pp. 425–426.

[5] Walcott, Chas. D., Smithsonian Miscellaneous Collections, vol. 64, No. 2, 1914, p. 111.

planes. Ripple marks were found in places and it is thought to be of clastic origin. The chief minerals are a fine recrystallized mosaic of quartz grains and amphibole needles. Its black color is probably due to graphite, for it contains but little magnetite (Plate XVII., *a*).

Bed No. 1, 25 feet thick, grades upward into bed No. 2 by becoming more granular in texture and by showing less regular bedding. The rock becomes hard and fine-grained and has a conchoidel fracture. Thin sections show it to consist of a mat of fine amphibole needless in recrystallized chert, with a very obscure granule structure. Magnetite occurs in these beds as a few scattered pebbles and in thin lenticular seams, but as a whole is present in small amounts. In places the rocks of this horizon are spotted, due to the presence of metacrysts of fayalite.

Near the top of these beds the transition into the Upper Cherty beds takes place by the texture becoming more granular, magnetite pebbles more numerous and layers of pure magnetite thicker and more abundant.

UPPER CHERTY BEDS.

Bed No. 1 of the Upper Cherty beds is characterized by (1) a granule texture, (2) the presence of conglomerate pebbles, (3) irregular wavy or lenticular character of the bedding, and (4) relatively high magnetite content.

Under the microscope the finer grained parts of the rock show the rounded forms attributed to altered greenalite (hydrous ferrous silicate). Mineralogically the material making up the granules is now the same as the bulk of the formation, namely amphibole, quartz and magnetite.

The conglomeratic nature of the beds is evident in many places, especially in the eastern part of the area studied. Many of the pebbles are of magnetite, many are of material resembling the bed below, and many show a core of siliceous granular rock with a zone of magnetite around the border. The shapes are mostly somewhat flattened and fairly well rounded, but a considerable number are angular, and plate-like. The size ranges

from one sixteenth of an inch up to six inches in diameter. Inasmuch as it marks no erosional unconformity, this conglomeratic horizon is of the intraformational type (Plate XVII., *b*).

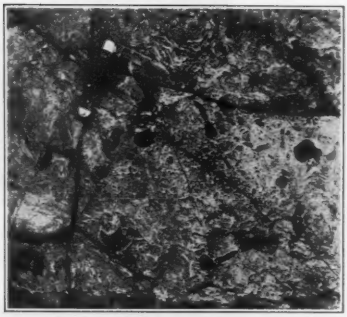
The individual beds pinch and swell, split up and unite, showing in all cases a wavy character, evidently not ripple marks nor caused by folding. There are no signs of cross bedding.

This bed makes up the greater part of the Upper Cherty beds, which as a whole, in the places where the data are most complete, are found to be high in magnetite as compared with any similar thickness of beds elsewhere in the Biwabik formation on the east Mesabi. Over considerable areas, bed No. 1 is found to have an average magnetite content of 30 per cent.

Bed No. 2 differs from No. 1 in having thicker beds of magnetite, many of them two inches in thickness or more. The conglomeratic character is marked in some outcrops. Hematite pebbles may be seen among the magnetite pebbles, and the reddish streak of some of the magnetic layers indicates the presence of some finely intergrown hematite. This bed averages 40 per cent. magnetite in places from which assays are available.

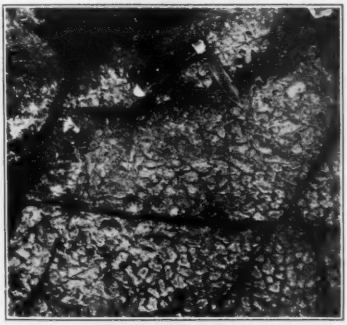
Bed No. 3 is a thin bed of cherty or jaspery material with a characteristic algal structure similar to but smaller than that of bed No. 3 of the Lower Cherty beds. Because of the hardness of this bed and the ones immediately above and below, it outcrops in many places. The color varies from gray to red, with the variation in the content of ferric oxide. In this horizon, the algal bodies resemble little piles of thimbles or inverted bowls one half to three fourths inch in diameter, piled in irregular columns about 6 to 12 inches high. Plate XVII., *c* and *d* show the characteristic forms. The upper and lower parts seem to merge into the granular fragmental material of the conglomerate. Between the finger-like structures, fragmental material also occurs. Horizontal sections of the structures show concentric rings like those of a concretion, but the vertical sections do not. Outcrops in the east Mesabi indicate a continuous bed fifteen miles long, and the structures are recognized in drill cores from thirty miles west of the area maped in this investigation. It is remarkable

a

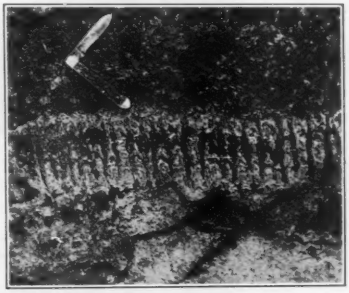


b

FIG. *a*. Thin-bedded "Intermediate slate"; bed No. 1 of lower slaty beds.
FIG. *b*. Conglomerate of bed No. 1, upper cherty beds.



c

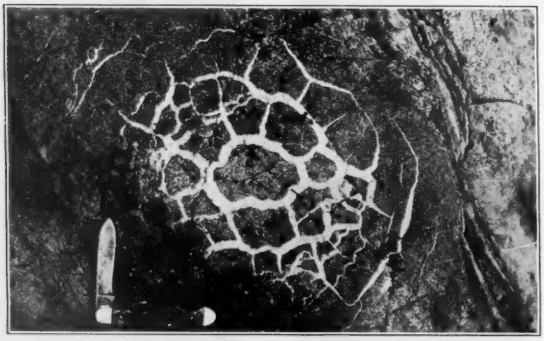


d

FIG. *c*. Horizontal section of algal structures in bed No. 3 of upper cherty beds.
FIG. d. Vertical section of algal structures of bed No. 3, upper cherty beds.

a

FIG. *a*. Nodules in thin beds in upper slaty beds.



b

FIG. *b*. Septarium from bed No. 1, upper slaty beds.

c

FIG. *c*. Drag folds in thin beds between massive chert layers in bed No. 1 of upper slaty beds.

that such small growths, forming but a thin layer, should extend over such a wide territory as to serve as a horizon marker for at least one-half the length of the range. Examination of cores from the rest of the range would probably show that the bed extends over the entire length of the iron formation.

Bed No. 4 is in nearly every respect the same as the magnetite rich bed No. 2, below the algal chert. The algal growth occurred at one stage during the accumulation of the conglomeratic beds.

UPPER SLATY BEDS.

Bed No. 1 of the Upper Slaty Beds is different in several respects from those just described. There is no abrupt change, however. The granule texture is seen in similar lenticular beds and there are even a few pebbles. Two features which distinguish these beds from the preceding are first, the magnetite layers instead of being lenticular and compact, are fine-grained and in many thin layers, a set of thin magnetite beds alternating with the lenticular beds of granule texture; second, the coarser beds contain and may consist of nodules or concretions distinct from the matrix. Plate XVIII., *a* shows these two features.

The nodules are not recognizable in drill cores, but they are very clear in the exposures and grade into the lenticular bedding in such manner as to suggest that the very lenticular beds in the Upper Cherty Beds may have developed by concretionary action. It is noteworthy also that the nodules and matrix have granules and even pebbles in them; so that the growth of a nodule does not apparently mean a replacement of all the material by a uniform precipitate from solution; rather it must have been more like a special cementation of a certain part of the beds.

One of the most striking features noted in the outcrops of the iron formation on the east Mesabi, is the septaria cracks in these beds. Septaria seem to have been described chiefly in carbonate concretions; and there may have been more or less carbonate in the iron formation—some still is to be found. However, the concretions are now mainly quartz and magnetite, while the cracks are filled with white quartz (Plate XVIII., *b*). They

serve to identify the horizon of outcrops over practically the entire east Mesabi, and it is believed that they will be found to extend over the whole range.

Other prominent features of these beds are the rather abundant garnets near the bottom, and the drag folding with more or less brecciation of the thin amphibole magnetite beds between the more competent layers of chert (Plate XVIII., *c*).

Bed No. 2 is similar in most respects to the septaria beds below. Drag folding and septaria have not been noted in them, and the magnetite content diminishes upward.

Bed No. 3 is chiefly made up of light green and white bands of amphibole and quartz. Magnetite is almost entirely lacking. Calcite is more abundant than in the lower beds.

Bed No. 4 is a limestone of variable nature, in places amphibolitic. It is soft and outcrops in few places, but all drill cores examined from east Mesabi holes starting in Virginia slate, show a thickness of 5 to 10 feet of limestone just above the iron formation proper. It is, therefore, taken as marking the top of the iron formation. In contrast with the variability of the iron formation below, the slate is very uniform in character for hundreds of feet above the limestone bed, so that the division between the Biwabik iron-bearing formation and the Virginia slate falls naturally at this horizon above the limestone.

As mentioned at the beginning of this article, the working out of the detailed stratigraphy of the central and western parts of the range from outcrops would be almost hopeless. Outcrops are few and the rock is weathered. However, underground workings, the walls of open pits, and the cores of thousands of drill holes would undoubtedly furnish material to continue the study on the main range which has been so well started by Wolff. The writer feels confident that many of the thirteen divisions of the iron formation which are recognized on the east Mesabi could be traced much farther westward. Features of drill cores from holes on the east Mesabi which were of most use in determining the various horizons (see tabulation) were the limestone bed, approximate content of magnetite (tested with ordinary small

magnet), thickness of the banding, presence of drag folds, brecciation, separia cracks, garnet, conglomerate pebbles, algal structures, spots of fayalite, black slate, and the basal granite or quartzite.

A brief examination of drill cores from scattered places showed that the magnetite content of the unweathered iron formation over the entire range approaches that of the eastern end. Large bodies of rock on the main Mesabi were found, not heavily overburdened, having 30 per cent. of magnetite. The common practice of discarding drill cores without considering their magnetite content is one which may be regretted, as it may become possible to mine and concentrate such material economically in the not distant future.

THE NATURE AND ORIGIN OF THE BIWABIK IRON-BEARING FORMATION OF THE MESABI RANGE, MINNESOTA.[1]

FRANK F. GROUT.

It has become the custom on the Mesabi iron range in Minnesota to call practically any phase of the Biwabik iron-bearing formation by the name "taconite." Certain enriched masses, constituting ore are exceptions, but even the "slate" and its altered equivalent the "paint rock," may pass as phases of taconite—the slaty taconite. Since the taconite is the protore from which the enormous deposits of the range are concentrated, its origin has received considerable attention.[2] Leith has made a great detailed microscopic study and has been able to some extent to reproduce certain phases in the laboratory. He has had the advantage, also, of wide experience in similar formations on other ranges. Most of the available material, however, has been the drill cores, and the wall rocks of test pits and mines. A few of these have been fresh and unweathered—to the disappointment of the owners, who usually drill in hope of finding leached, enriched ore. In the available material, however, the proportion of taconite which is quite fresh and unaffected by weathering is relatively small. The average taconite specimen is much oxidized but not much enriched.

On the east Mesabi actual outcrops of unweathered taconite

[1] Published by permission of the Director of the Geological and Natural History Survey of Minnesota.

[2] Winchell, N. H., and Winchell, H. V., "Iron Ores of Minnesota," Geol. and Nat. Hist. Survey of Minn., Bull. 6, 1891.

Spurr, J. E., "The Iron-bearing Rocks of the Mesabi Range," Geol. and Nat. Hist. Survey of Minn., Bull. 10, 1894.

Leith, C. K., "The Mesabi Iron-bearing District of Minnesota," U. S. Geol. Survey, Mon. 43, 1903.

Van Hise, C. R., and Leith, C. K., "The Geology of the Lake Superior Region," U. S. Geol. Survey, Mon. 52, 1911.

are numerous, and the recent examination of large masses of fresh material in this eastern area, by the Geological and Natural History Survey of Minnesota, has revealed a few features that are significant as to the origin of the taconite. The following discussion applies chiefly to the perfectly fresh unoxidized taconite.

The broader geologic relations of the taconite are generally known from the work of Winchell and Leith. On the east, the Giants range granite is the basement below the Upper Huronian sediments. A thin layer of Pokegama quartzite occurs in some places, just below the iron-bearing formation. The unconformity above the granite is conspicuous in many outcrops. The iron-bearing formation, 350 to 550 feet thick, is known as the Biwabik formation. The detailed stratigraphy and general characters of the beds are reported by Dr. T. M. Broderick,[3] who was associated with the writer in these studies.

MINERALS.

Probably ninety-five per cent. of the fresh unweathered taconite at the east end of the range consists of quartz, amphibole and magnetite. Other prominent minerals are garnet, fayalite, graphite, pyroxenes and carbonates. Less abundant are micas, feldspars, chlorite, pyrite, kaolin and a few rare contact minerals. Greenalite is prominent to the west, where it shows the characters well described by Leith.[4] Its alteration to amphibole on the east end of the range is probably due to contact action of the gabbro. Hematite, similarly, is more abundant in the west, as compared with magnetite, though the magnetic oxide is widespread.

Quartz occurs in a variety of forms and at all horizons. Fragmental grains of quartz sand are rare except near the base of the formation.

The chief amphibole is actinolite, though others are not rare.

[3] Broderick, T. M., "Stratigraphy of the Biwabik Iron-bearing Formation," ECON. GEOLOGY, preceding article.

[4] Leith, C. K., *op. cit.*

This occurs in minute needles constituting large felty masses of amphibolite, as well as disseminated in much of the quartz. Some obscure remnants of granular forms are marked by the arrangement of amphiboles along the former boundaries of the granules. Recrystallization near the gabbro produced many large green amphibole crystals, several inches across.

The iron oxide, which is attracted by an ordinary hand magnet, is here assumed to be magnetite. Near the base of the formation magnetite occurs in grains that appear to have been fragmental when the formation accumulated. Much more of the magnetite is disseminated and apparently developed by alteration of some very different original deposit. In the best magnetite concentrations, numerous layers of nearly pure iron oxide, about one fourth of an inch thick, alternate with the more siliceous layers. The beds vary, however, from the thinnest papery layers, to beds six inches thick.

Hematite occurs in the unweathered taconite as black, fine-grained intergrowths with magnetite, distinguished chiefly by its red streak.

Garnets of a brown color form rough crystals and crystaline masses, some of which are an inch or more in diameter.

Fayalite forms metacrysts, yellow when fresh and brown when weathered, usually about the size of a pea. The grains have thousands of inclusions of quartz and amphibole. Some have also magnetite.

Graphite colors many of the slaty and cherty layers and concretions. Even some black pebbles resembling magnetite are colored by organic matter.

Apatite is not visible in most of the thin sections, but has been detected in the coarse recrystallized ore at the east end of the range.

Carbonate grains are disseminated at certain horizons in the taconite, but are abundant only in the upper ten feet. Calcite is the chief mineral, but some weathered grains are brown as if the siderite molecule was present.

ROCKS.

The local name taconite will be retained here as a general convenience, to designate any phase of the Biwabik iron-bearing formation, consisting of mixtures of these minerals. Probably no elaborate additions to the nomenclature are desirable, though the terms used are not wholly satisfactory. There are small masses properly described as conglomerate, quartzite, and slaty shales, with a variety of impurities. There are large quantities of amphibolites and amphibole-magnetite rocks, and still larger bodies of highly siliceous rocks that have been classed as cherts, with various mineral qualifiers to indicate the impurities. When these chief rocks of the formation are carefully studied the names given seem less suitable than they appear at first glance. Only a small amount of material seems to have had the texture or origin of the more common cherts of the post-Algonkian sediments. The only parts of the formation that seem to have been originally cherty are one or two layers as much as 15 feet thick and some concretions in other layers. Most of the formation shows traces of a granule texture, with grains from microscopic size to six inches across. It is confusing to class together as cherts, rocks which once differed so widely as cherts and conglomerates. Furthermore, a good deal of the formation is so far recrystallized that the quartz is no longer as fine grained as typical chert. The writer's preference is, therefore, to use the local name taconite for the material, with more or less complicated qualifiers to show the varieties.

ORIGIN.

Clastic grains, such as pebbles and quartz sand from older formations, appear only in the lowest beds of the formation (Plate XIX., *a*). However, there is a gradation from these beds to the more typical taconite, and the bedded structure, with the mineral composition, is evidence enough so that it is generally agreed that the formation is to be classed as a sediment rather than as an igneous rock.

The cherts and primary iron deposits are materials known to be precipitated from water solution, and to explain the differences

between the taconite and more common mechanical sediments, is it assumed that the original deposition of the formation was largely a process of precipitation. The solution of silica is facilitated by the presence of alkalies; that of iron would be more likely in the presence of acids. For a combined solution the most probable solvent suggested is an alkaline bicarbonate solution. Such solutions result both from weathering and from igneous emanations, and are, therefore, not conclusive as to the original source of the solvent or of the iron.

The source of the iron in the solutions that supplied the Biwabik formation is discussed at length by Van Hise and Leith.[5] They conclude that, for the iron of unique, thick, extensive formations like this, it is necessary to appeal to contemporaneous basic, igneous rocks. They believe large amounts of iron came into the solution as direct magmatic emanations. Their conclusions are not based on the study of the Mesabi ores alone, but on a knowledge of a wide variety of iron deposits. Moore has recently contended that the evidence is not conclusive, and maintained that lateritic weathering is capable of supplying the iron.[6] The recent studies of the Mesabi range give no new evidence, but, as has been noted before, the only contemporaneous igneous rocks are at a considerable distance from the range.

Precipitation.—From any assumed solution, reactions may be suggested that will precipitate silica and iron.[7] The direct evidences of the actual form of the precipitate and nature of the precipitating agent, are very slight. Leith emphasizes the granular forms of greenalite, which he duplicated more or less accurately by laboratory experiments with inorganic solutions. There are also the supposed algal forms in the cherts and jaspers indicating organic action. Their nature has been discussed elsewhere.[8] There are the graphitic slates and cherts indicating

[5] *Op. cit.*, pp. 506–518.

[6] Moore, E. S., "The Iron Formations of Belcher Islands, Hudson Bay," *Jour. Geology*, vol. 26, p. 412, 1918.

[7] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 519–527.

[8] Grout, F. F., and Broderick, T. M., "Organic Structures in the Biwabik iron-bearing formation of the Huronian in Minnesota," *Am. Jour. Sci.* In press.

organic material. Harder and Johnston emphasize the probable precipitation of ferric oxide and silica as primary deposits in some iron-bearing formations, associated with more or less organic matter.[9] Steiger[10] reports organic matter in some greenalite rock. Since it seems that organisms could live at that time and bacteria are known to precipitate iron at the present time, it may be assumed that organisms played a part also in the deposition of the iron of this formation. This is not certain, because the deposits seem to have been more or less modified since their first deposition, and their original form is in doubt; but current studies seem to indicate that if a reaction may occur both organically and chemically, it occurs more rapidly and completely by the action of organisms. Charles Schuchert, writing in regard to the cherts which seem to have organic structures, raises the question of the nature of the precipitate and its effects on the organism.[11] "The iron probably killed off the growths after much accumulation, and then a young new layer grew over the older one, only to fill up the cells in the course of time by another accumulation of iron." Whether the iron was deposited by organic action, or interfered with the organism, it was apparently deposited alternately with precipitated bands of chert. It is therefore believed that the cherts were precipitated by organisms, and that they were more or less ferruginous as first formed.

The several parts of the formation differ so widely that the several suggestions as to primary precipitation may each be correct for certain beds.[12] Probably the deposits most nearly in primary condition are the algal cherts. The greenalite, the beds of iron oxide and the ferruginous carbonate seem to be more likely modified since their original precipitation.

Conditions of Deposition.—The extent of the iron-bearing formation indicates deposition on a broad sea bottom. It lies above

[9] Harder, E. C., and Johnston, A. W., "Geology and Iron Ores of the Cuyuna District, Minnesota," U. S. Geol. Survey Bull. 660A, p. 16, 1917.

[10] Steiger, George, see analysis in U. S. Geol. Survey Mon. 52, p. 167.

[11] Personal communication.

[12] Spurr's argument that all phases were derived from a single original type has been abandoned. See *op. cit.*, p. 44.

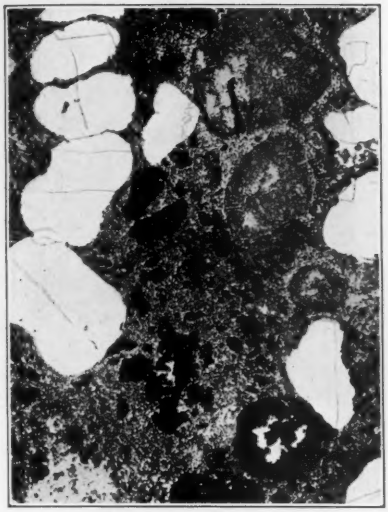
a sand and below a clay, as a part of a series of sediments, probably formed in shallow water. Van Hise and Leith[13] consider the water probably shallow, because of the dominance of silicates over carbonates, the structural differences from the Cuyuna iron formation, and the lack of outcrops farther north. An additional evidence appears in the flat form of pebbles in the central conglomerate.

Texture of the Deposit.—The cherts with algal structure appear to be primary in their form and texture. Much of the rest of the formation is filled with granules, pebbles, concretions, and nodules, indicating more or less reworking since precipitation. Throughout most of the formation the granules uniformly show certain mineral and structural peculiarities which have led to the suggestion that they are not ordinary fragmental sedimentary grains (Plate XIX., *b*). Leith has argued that the granules of greenalite are forms that may develop in colloidal precipitates by surface tension. No doubt there are granules that are best explained as forms resulting from surface tension on precipitates, but there are also many pebbles which could not have formed from any process other than mechanical wear (Plates XIX., *c*, and XX., *a*, *b*). Associated with fragmental pebbles, granules of similar fragmental origin are certain to be numerous. Spurr early recognized that the granules were of several types of origin.[14] About one fourth of the formation on eastern Mesabi range has a notably pebbly texture (Plate XX., *b*).

The Alternation of Deposition.—The alternation of sediments of several sorts in the iron formation as a whole indicates a probable alternation in the source of supply. The larger alternation of slate and chert shows that deposition occurred under different conditions. On the other hand there is a smaller more often repeated alternation of magnetite with granules or pebbles, which more likely indicates a seasonal or occasional alternation of conditions.

Primary Modification of the Deposit.—As was just suggested,

[13] Van Hise, C. R., and Leith, C. K., *op. cit.*, pp. 214, 604, and 613.
[14] Spurr, J. E., *op. cit.*, p. 143.

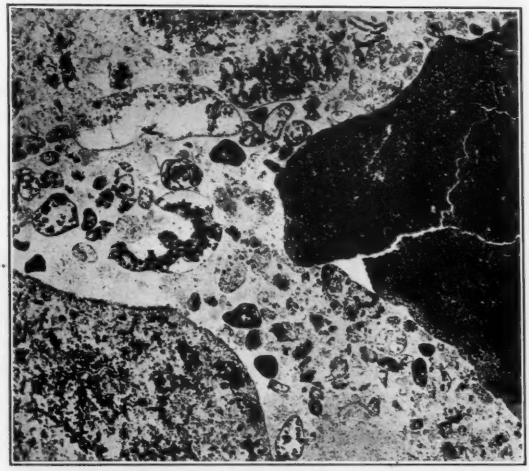


a

b

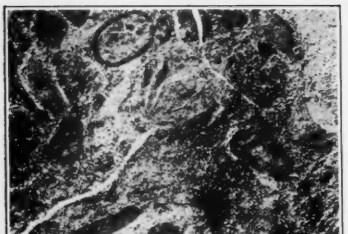
FIG. *a*. This section showing granules of quartz, magnetite and amphibole side by side in the lower beds of the formation. Magnified 15 diameters.

FIG. *b*. Granules of altered taconite. Note the septaria-like cracks and enrichment. Magnified 15 diameters.

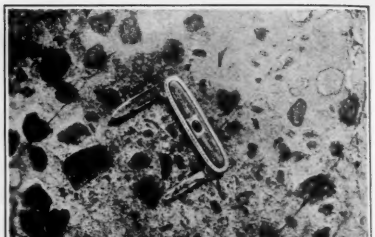


c

FIG. *c*. Coarse pebbles in thin section showing the same structures as the granules. Magnified 15 diameters.

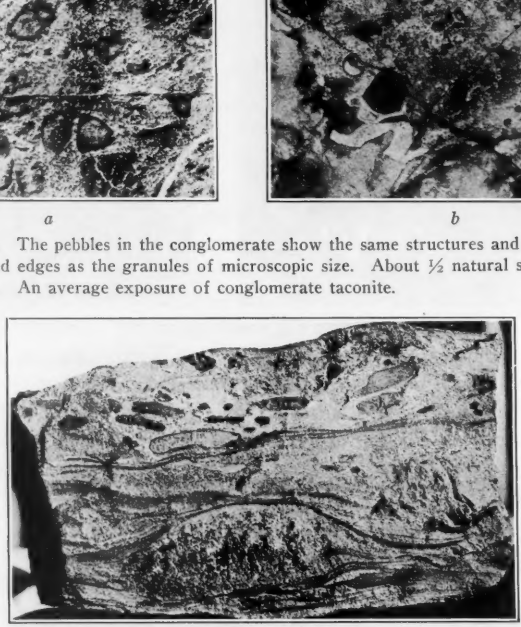


a



b

FIG. *a*. The pebbles in the conglomerate show the same structures and blackened edges as the granules of microscopic size. About ½ natural size.
FIG. *b*. An average exposure of conglomerate taconite.



c

FIG. *c*. A vertical exposure of conglomerate taconite showing elongated pebbles in nearly horizontal position. About ½ natural size.

d

FIG. *d*. The bedding of the conglomerate taconite is very irregular and in many places slightly broken.

the repeated alternation of material in the beds now found is believed to be a significant fact in connection with the history of the formation. There are hundreds of alternations of fine magnetite and coarser fragmental layers. Rhythmic sedimentation is in some cases due to a rhythmic supply of differing materials. In a broad way, the supply may be ferruginous at one time, slaty at another, and cherty at another. If the material had been derived from volcanic sources, as has been suggested, it seems hardly likely that these supplies would alternate as many times as the sediments indicate. It is unlikely that there were so many successive flows. Volcanic rhythms should produce alternations on a large scale. Climatic rhythms also are larger features. The detailed alternation of beds from a tenth of an inch to six inches thick is more likely attributable to seasonal or occasional changes in conditions. These changes would affect a chemically depositing sediment only if in shallow water, and emphasize the conclusion reached above as to the conditions of deposition.

The detailed structure of the conglomerate and granular beds is suggestive as to the conditions that must have prevailed. Most of the pebbles are flat, and they vary widely in the degree of rounding (Plate XX., *b*). They include no fragments of the neighboring granite and schist, but many closely resemble the beds of iron-bearing formation close below. Their size and angularity indicate no distant source. The irregularity suggests washed lumps of partly hardened mud, or precipitate. The most probable source of the pebbles is a part of the formation itself. However, no signs of erosional unconformities have been found in the iron formation. Such a conglomerate is to be classed as intraformational—one formed of material recently deposited and without any extensive transportation. Such conglomerates are reported from several limestone formations with characteristics that are so similar as to warrant giving this siliceous bed the same name.[15] The conglomerate part of the formation, as well as some of the granules, may therefore be attributed to a recent precipitate more or less broken up by wave action. The

[15] See, for example, Foerste, A. G., "Intraformational Pebbles in the Richmond Group," *Jour. Geology*, vol. 25, p. 289, 1917.

freshly broken fragments would be large and angular pebbles, those washed about for a longer time would be more rounded, and the smaller grains would become rounded granules.

Most of the pebbles are magnetite. This might mean that an original ferruginous layer resisted the breaking action of the waves longer than some of the freshly deposited silica. Other pebbles, however, suggest another explanation. Many pebbles are cherty with a border of magnetite. It seems that at the time the pebbles were rounded (or possibly since then) some process *enriched* them in iron (Plates XIX., *b*, and XX., *a*). Since it is believed that the pebbles formed in shallow water, the logical explanation is that standing water acted on the ferruginous chert, enriching it, much as the ores of the Lake Superior region are being enriched at the present day—by solution of silica, and possibly, but only to a small extent, by deposition of iron in its place.

This assumption of leaching of silica in a sea where silica was being deposited, would not appear plausible unless, as in this case, some alternation of conditions is clearly indicated. In a shallow sea the contribution of iron and silica from a magma may furnish plenty of material for deposition; but at a distance from the magma source, any addition of fresh water (say from a heavy rain on the adjoining land), would crowd back the depositing solutions and replace them by water that would dissolve and oxidize the deposits.[16] Diffusion and convection would soon bring back the stronger solution. The volume of fresh water which leached the silica may not have been great enough to modify the composition of the depositing solution very much, after it was mixed by diffusion and general circulation. So the next deposit of iron is not necessarily leaner, or more siliceous than the first. Occasional storms might agitate the waters enough to break up the deposits and round the grains, but the special richness of the conglomerate in iron oxide is thought to be due to a primary leaching of the silica rather than a difference in the original deposit. The enrichment is considered primary

[16] Van Hise and Leith note that some greenalite was probably oxidized at the time of deposition. *Op. cit.*, p. 537.

because it is believed to have occurred before the overlying layer was deposited. While this enrichment is chemically the same, it is not such an enrichment as has occurred on the main Mesabi range in late geologic periods. That enrichment has been accomplished by circulating ground waters, and may be as deep as the waters carry solvent action. The primary enrichment here considered probably occurred at the bottom of shallow standing water and its effects were superficial. Nevertheless if each thin

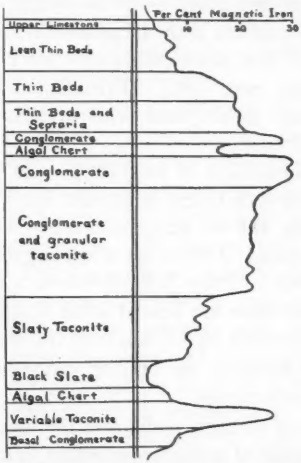


FIG. 30. A curve showing the relation of magnetite to the conglomerate in a well explored section of the Biwabik formation.

bed is superficially enriched, the formation as a whole shows the effect. From this point of view the magnetite pebbles may be those which were most thoroughly leached. The best magnetite is so characteristically associated with conglomerate that there is a strong suggestion that the primary taconite has rich layers only where primarily leached (Fig. 30).

In continuation of this argument, it is well to consider the end products of such processes of leaching and wave action as are here suggested. Eventually the silica might all be leached from

a surface layer, and the residual iron compounds, thoroughly oxidized, might be fairly well pulverized. The conditions in deep water might also have been such that a little leaching of silica occurred, leaving only a layer of iron oxide along the bottom. When deposition was resumed, this powdery ferric oxide, however formed, would lie on the irregular bottom as a layer of relatively pure ore. This is exactly the condition of the magnetite beds now alternating with conglomerate.

The suggestion here given as to the origin of the pure magnetite in no way conflicts with the possibility, suggested by Van Hise and Leith,[17] that some oxide may have been precipitated directly in a very pure form. Precipitated oxides, however, would be expected to alternate with precipitated chert rather than with a conglomerate.

After any accumulation of oxides, the next precipitate would tend to cement any such layers of powder into more or less gelatinous or hard rock, and the next storm might break them up into pebbles of iron oxide. This is the effect suggested by such outcrops as are shown in Plate XX., *d*, where a bed of magnetite stops abruptly and there are near it some fragments that appear to have been just broken off. Thus both the enrichment of chert pebbles and the breaking up of iron oxide beds, furnish ore pebbles to the conglomerate.

The development of chert nodules in the magnetite deposits is probably not a phase of primary deposition, but is believed to be an effect that developed soon after deposition. In the main conglomerate beds, no clear nodules have been noted, but in the beds above the conglomerate they are numerous. The nodules are mostly elongated and show gradations into continuous beds of similar material. Both the rounded forms and the irregular layers contain septaria cracks. Between the nodules are thin beds of magnetite, and the nodules themselves contain iron oxide in scattered grains. The peculiarity of the nodules is that though rounded and elliptical in outline, the internal texture is granular like the matrix and finer parts of the conglomerate. It is evident

[17] *Op. cit.*, p. 527.

that there was a fragmental accumulation which has been incorporated or included in a nodular cement.

There is a conspicuous irregularity in the bedding (Plate XX., *d*) which is probably more related to these several primary modifications than it is to the original precipitation. Solution surfaces resulting from leaching, normally show rounded forms; concretions are irregularly rounded, and the compression of loose sediments against rounded lumps would no doubt produce some such wavy bedding planes. Considerable irregularity may be due to the shrinkage of voluminous colloidal precipitates during consolidation and recrystallization. The septaria cracks show that some such shrinkage occurred.

Metamorphism.—It can hardly be assumed that the primary deposition and reworking of the iron resulted in magnetite. There is every reason to believe that the precipitate was a chert, with more or less ferrous silicate and carbonate and limonite. The oxidation and formation of intraformational conglomerate probably produced limonite. The change from these minerals to amphibole, quartz and magnetite is a kind of metamorphism that may occur in several ways. Probably the ferrous iron of the silicate and carbonate reacted directly with the more oxidized limonitic beds to form magnetite. If the primary oxidation was very complete, a reducing agent is available in the organic matter, known to have been present in certain beds. These and other reactions have been sufficient during the long ages of recrystallization under heat and pressure, to make most of the iron oxide of the Mesabi formations magnetite.[18] However, not all the iron oxide is magnetite, and even adjacent pebbles may differ in their state of oxidation. This is no doubt due to some difference in hydration or association of the pebbles as primarily deposited.

Dynamic metamorphism is indicated by some folded layers and tension cracks. Scattered veinlets of quartz and magnetite probably developed under conditions of great heat and pressure.

[18] This is not recognized by Van Hise and Leith. It is not necessary to appeal to the reduction or oxidation by water as suggested by them, *op. cit.*, pp. 172 and 527.

The contact metamorphism of the formation as a whole has occurred where it was approached by the Duluth gabbro. The chief effect seems to be an increase in the size of grain and reduction in porosity.

RÉSUMÉ OF THE HISTORY.

The deposition of taconite probably occurred in shallow water mainly by precipitation through organic processes, resulting in lean ferruginous cherts, with more or less iron-bearing carbonate, ferric oxide, and greenalite. Alternating with periods of precipitation came periods of solution, leaching, oxidation, and wave action, producing intraformational conglomerates, and granular rocks much higher in iron than the original precipitate, and probably some layers of pure ferric oxide.

The richer deposits of magnetite occur so characteristically in the granule and conglomerate zones that it seems probable that the primary leaching was a determining factor in the development of primary iron concentrations from lean ferruginous cherts, and greenalite rock.

When the sediments were covered with other layers, there may have been more or less concretionary rearrangement. Deep burial under slates, developed heat and pressure that recrystallized a good deal of the formation.

The primary minerals reacted during metamorphism in such a way that most of the iron oxide is now magnetic. It seems likely that enough ferric oxide was present to produce all the magnetite now found, by direct reaction with the ferrous minerals and organic matter, that are present in excess.

The recrystallization also resulted in shrinkage cracks. Some regional movements developed folds. Contact action by the Duluth gabbro and sills made a great difference in the texture of the deposits at the east end. None of these processes involved any apparent change in the general composition of the taconite. Erosion has more recently exposed the metamorphosed beds to weathering.

ORE DEPOSITION AND ENRICHMENT AT THE EVERGREEN MINE, GILPIN COUNTY, COLORADO.[1]

D. H. McLaughlin.

INTRODUCTION.

In the Evergreen Mine in Gilpin County, Colorado, copper ores occur which have attracted the attention of geologists during the last few years on account of the intimate association which exists there between the sulphides of copper and the apophyses of a neighboring stock of monzonite. The copper minerals, chiefly bornite and chalcopyrite, occur largely in two small dikes and in the matrix of an igneous breccia formed by the complex intrusion of the molten mass into the walls of shattered schist and pegmatite.

The Evergreen Mine is near the little town of Apex, at an altitude of 9,700 feet, about seven miles east of the Continental Divide. The mine has been operated in a small way for twelve years or so. A shaft about 350 feet deep has been sunk, and levels run at 100 feet, 200 feet and 350 feet respectively. A little ore has also been mined from a tunnel penetrating the deposit from a point on the surface north of the shaft. A small mill has been erected but little ore has been shipped.

The ore-body outcrops on the side of a shallow valley of the older cycle of erosion in a region of moderate topographic relief, but still above the actively cutting portions of the youthful streams of the Front Range. The climate is severe. Snow lasts for seven months, but temperature in the underground workings is rarely below the freezing point.

[1] The work embodied in this paper was done in connection with field and laboratory studies for the Secondary Enrichment Investigation. The thanks of the author are due to Professor L. C. Graton for valuable aid and criticism.

The deposit is in the wide area of pre-Cambrian rocks which form the greater part of the Front Range. The oldest formation is a fine-grained biotite schist, believed to be of sedimentary origin. Into it are intruded several plutonic rocks also of pre-Cambrian age showing various degrees of metamorphism. Pegmatitic intrusions associated with the granite are prominent, in places as broad dikes tens of feet in width, elsewhere as fine laminæ cleaving the fissile schists. The only rocks later than the pre-Cambrian are various early Tertiary intrusions, chiefly monzonites in character, which form many small stocks and dikes. The chief ore-bodies of the region, the gold-silver veins and the tungston veins are closely related to these intrusives.

In the first published description of the deposit, a paper by E. A. Ritter,[2] the opinion was expressed that the ores are primary constituents of the intrusion rock, and crystallized directly from the magma with the rock minerals. The unusual concentration of the sulphides is regarded as a segregation caused by sublimations from the magma.

Bastin and Hill, in a later article,[3] add new data concerning the mineralogy of the ore, and come to some interesting conclusions regarding its genesis. The colorless pyroxene of the intrusive was shown to be wollastonite and its occurrence with garnet was regarded as suggestive of the digestion of calcareous wall-rock by the magma, probably encountered in depth before it reached its present position. The authors support Ritter's view that the sulphides are primary constituents of the dike rock, but they believe them to have been derived either from the wall-rock at depth by absorption or from the magma by differentiation. Their conclusion is: "The deposit . . . represents an endomorphic effect produced by contact metamorphism at the border of a large intrusion of monzonite."

The mine was visited in the summer of 1916 by the present author accompanied by Professor Horace B. Patton, and the

[2] E. A. Ritter, "The Evergreen Copper Deposit, Colorado," *T. A. I. M. E.*, vol. 38, pp. 751–765, 1907.

[3] E. S. Bastin and V. M. Hill, "The Evergreen Copper Mine, Colorado," ECON. GEOL., vol. 6, pp. 465–472, 1911.

results of the observations in the field and subsequent laboratory study of the material collected are embodied in this paper. In general, the observation and conclusions are in agreement with the previous writers, but it is believed that the somewhat different viewpoint with which the problems are attacked makes this presentation permissible and perhaps justifies some degree of repetition.

DESCRIPTION OF THE DEPOSIT.

Associated Rocks.—The wall-rock of the deposit is pre-Cambrian biotite schist with numerous tabular and lenticular intrusions of a siliceous pegmatite. Although none of the thin sections show the schist without some alteration due to the mineralizing fluids, the original rock may be readily inferred to be composed of a deep brown-green biotite and a fine-grained aggregate of quartz with some orthoclase. The pegmatitic material is chiefly quartz and orthoclase in coarse irregular masses.

To the east of the mine, a stock of monzonitic outcrops and the two dikes, with which the ore is associated, are probably apophyses of this stock. The dikes strike a little west of north and dip steeply (60–70 degrees) to the east, being approximately parallel both in strike and dip to the structure of the schist. The dikes are about twenty feet apart. The one to the east is the larger, averaging 12–15 feet thick, while the one to the west varies from a few inches to about three feet.

In places the wall-rocks are penetrated by the igneous material, producing masses of igneous breccia often of notable extent. The rocks between the two dikes have suffered this brecciation particularly. Places were observed in which the identity of the dikes themselves became lost in a confused mass of this shattered schist. All gradations exist from the ratio of wall-rock to intrusive in which the schist fragments are properly described as inclusions, to the conditions in which the wall-rock predominates, and the igneous rock fills irregular fractures in it. The schist and pegmatite appear as if shattered by violent explosions and then cemented by the intrusive rock. The fragments of the brec-

cia vary from small chips, a fraction of an inch in thickness, to blocks a couple of feet wide.

The normal dike rock is a fine-grained hypidiomorphic granular rock of a medium gray color with small feldspars and pyroxenes visible with the hand lens. For the most part it is even-grained but in places there is a subporphyritic development of the orthoclase. Under the microscope the unmineralized rock is seen to contain orthoclase as the chief constituent (in part microperthitic with albite) with somewhat less abundant quartz. A small amount of oligoclase is sometimes present. Green augite (non-pleochroic or only faintly pleochroic) is the most abundant dark mineral, but a little pale blue-green amphibole was observed in one side and a few laths of deep green biotite. Titanite crystals and prisms of apatite and zircon are common accessories. The orthoclase grains average about 0.5–0.75 mm. in longest diameter with a maximum of about 1.5 mm., the quartz usually about 0.5 mm., and the pyroxene 0.3 mm., with a maximum of 1 mm. The rock seems more nearly a granite in composition than a monzonite.

Approaching the ore-bodies the dike rock becomes somewhat alkaline in character, with aegirite-augite and fine laths of wollastonite usually in great abundance. In the hand-specimen, it is a light-colored, fine-grained rock with a peculiar pearly luster, distinctly different from a normal feldspathic rock. In some cases, the laths of wollastonite are sub-parallel; in others they form an interlacing mass. Orthoclase, with some microcline, quartz, wollastonite, and the deep green aegirite-augite are the chief component of the rock. A little plagioclase (oligoclase-albite), wedge-shaped titanite and small crystals of zircon are accessory. Apatite is abundant, in some cases as large grains. The aegirite-augite forms small stubby crystals, usually with a pale green, non-pleochroic core which is in striking contrast to the deep green tints of the outer portions of the grain. The feldspars and quartz are in the usual hypidiomorphic relations, and of about the same grain as described for the normal rock. The wollastonite, which is the most unusual feature, is in long laths (maxi-

mum about 0.75 mm.) commonly in subparallel orientation. It is most ordinarily grouped along the contacts of the grains and tends to avoid the quartz although a few prisms penetrating the latter were observed. In some cases it projects into the feldspars. The subparallel structure shown by the wollastonite is not shown by the other rock minerals except to a slight degree.

The dike rock containing the sulphides, and the rock forming the igneous breccia is the aegirite-augite and wollastonite bearing phase of the granite. For the most part, the thin western dike (the main Evergreen dike) consists entirely of the wollastonite bearing rock, but on the 200-foot level, where a drift has been pushed several hundred feet to the northwest along it, the rock changes without any distinct boundary into the normal gray granite. In one place the change required about ten feet; in another it was apparent within the dimensions of a hand-specimen.

Bastin and Hill mention finding abundant garnet in the dike rock and in the breccia, but in the thin sections of the material studied in this case, garnet was not an important mineral, while apatite seemed more abundant than would be expected from the earlier descriptions. The rock associated with the ore was named Evergreenite by Ritter, who believed the wollastonite to be enstatite and diallage. It was shown to be wollastonite by the work of Bastin and Hill.[4]

Alteration of Rocks near Sulphides.—The bulk of the sulphides occur in the "evergreenite," usually not in the dikes themselves, but in the irregular intrusions in the brecciated wall-rock. The inclusions of schist or pegmatite contain fine seams of chalcopyrite or disseminated specks of chalcopyrite and bornite, but the larger masses of the ore-minerals occur only in the igneous matrix itself. The rock associated with the ore contains numerous miarolitic cavities and in places develops a coarser structure suggesting pegmatitic tendencies. The occurrence of micropegmatite in these rocks mentioned by Ritter is in accord with this observation. In the miarolitic cavities, crystals of orthoclase with crocidolite and imperfectly formed crystals of bornite and

[4] *Loc. cit.*

chalcopyrite between them were observed in a few cases. Fluorite occurs in small grains in the intrusive usually in the miarolitic portion. A few small particles observed in the thin sections are believed to be tourmaline, but were not positively identified.

Hydrothermal minerals are not common, but epidote is associated with the bornite grains, replaces the feldspars and pyroxenes, or cuts across the rock in veinlets. Sericite is somewhat developed in the feldspars but on the whole it is not very abundant. In one or two cases, laths included in the outer portion of bornite grains were observed, but evidence was lacking whether they should be regarded as replacements of the bornite or interpreted as inclusions. If the latter interpretation is accepted they indicate the extension of the period of bornite formation into the period of conditions favorable for sericite (*i.e.*, hydrothermal).

Calcite is common throughout the ore-bearing rocks. It attacks the wollastonite with especial vigor, and in many specimens only the lath-like forms assumed by the calcite give any clue of the former existence of the earlier mineral. The calcite is later than the epidote and is probably a product of the closing phases of the emanations which formed the ore.

As seen in the field and in the hand-specimen, the schists present fairly sharp boundaries against the invading dike-rock, but in a few places intimate injections along cleavages of small fragments have reduced them to mere bands of the dark constituents (chiefly biotite) floating in coarser-grained bands of the intrusion. Under the microscope, a blue-green amphibole was often observed in the schist. It occurs in irregular broad grains up to 0.5 or 0.75 mm. in length and commonly contains abundant inclusions of fine flakes of the biotite of the schist. The optical properties of the amphibole fail to identify it with any of the ordinary varieties. Its similarity to the amphibole observed in the normal granite, and the inclusions of biotite favor the view that it is a product of emanations from the intrusive reacting with minerals of the schist.

The borders of the schist inclusions may often be seen, with

the aid of the microscope, to be lined with fine grains of deep green aegirite-augite. Fine grains of augite are abundant throughout the inclusions, but, as they occur along veinlets in a few places and seem closely related to the aegirite-augite near the margins, they were probably introduced from the magma.

The pegmatitic material associated with the schist is little altered by the mineralizing processes. Masses of coarse quartz which occur in certain of the brecciated zones are probably inclusions of these older dikes.

Epidote and sericite are developed to slight degrees in both types of the wall-rock. The fine-grained feldspars of the schists are especially susceptible to the attack of the sericite but they and the other minerals of the schists usually show less alteration to epidote than do the minerals of the igneous matrix.

Ore-minerals.—The bornite and chalcopyrite are present in approximately equal amounts. The two minerals for the most part exhibit mutual boundaries toward each other. Their contacts are sharp and definite, with smooth unbroken lines, and blunt penetrations of the chalcopyrite by the bornite are as common as the reverse relation. In a number of specimens the graphic structure is developed, usually with the chalcopyrite as the host mineral and with the bornite as the smoothly irregular blebs. (Plate XXI., *a* and *b*.) When these structures are studied, it is difficult to avoid the opinion that the two sulphides are contemporaneous in origin.

However, in a fair number of cases, bornite was observed to form broad margins along gangue veinlets, now completely altered to calcite, which cut chalcopyrite area. (Plate XXI., *c* and *d*.) The deduction that this bornite is later follows inevitably, and it is also clear that the bornite is of the same age or later than the original gangue mineral in the vein. No break can be detected between the bornite of the areas showing the mutual boundaries or the graphic structure, and the bornite of the veinlets. The most acceptable hypothesis to me is that throughout the chief mass of the ore the two sulphides were first deposited together, but, with changing conditions,—probably due to the

relative decrease of iron with respect to copper in the ore-depositing solutions,—the chalcopyrite ceased to form and tended to alter to the richer copper mineral bornite, which continued to form alone to a slight extent under the later modified conditions.

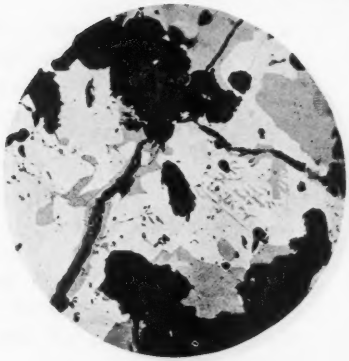
The question may arise if there is any possibility that the bornite which replaces the chalcopyrite is of secondary origin, *i.e.*, deposited from cold descending surface waters. In a deposit exposed only to a depth of 200 feet, this possibility can not be absolutely eliminated, but the slight amount of secondary chalcocite in the ores, the lack of any special relations between the bornite veins and the chalcocite, the association of the bornite with hydrothermal minerals, and the rarity of bornite as a secondary mineral elsewhere argue convincingly against this view.

The bornite is confined almost exclusively to the dikes or to the igneous matrix of the breccia. The chalcopyrite, however, is not uncommon as seams or finely disseminated grains throughout the schist inclusions. This may be considered to indicate that the alteration of the schists took place chiefly during the early intense phases of the intrusion, while the bornite was subordinate to the chalcopyrite. The intense alteration of the minerals of the schists to amphibole and augite, with the much slighter development of sericite and epidote is parallel evidence supporting this interpretation, but both of these relations may possibly be due entirely to the chemical differences in the host rock.

Tetrahedrite, galena and sphalerite occur in small amounts with the bornite and chalcopyrite. The tetrahedrite and galena are probably contemporaneous with the bornite, for they occur through it as scattered blebs, in places abundant enough to develop small areas of the graphic structure. This is especially noteworthy in the case of the galena. The sphalerite on the other hand is most closely associated with the chalcopyrite which it often contains as abundant very fine inclusions.

Magnetite and pyrite occur only as small grains in the schist where they are probably either original constituents or products of earlier mineralizing processes not related to the Evergreen ores.

a

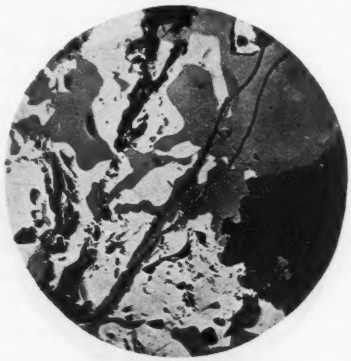


b

FIG. *a*. Bornite blebs (dark) in graphic patterns in chalcopyrite (light). Secondary chalcopyrite (light) developing in bleb in upper part of field. Note shrinkage cracks. Magnified 38 diameters.

FIG. *b*. Bornite (dark) in large areas, in graphic structures, and along gangue veinlets (black) in chalcopyrite (light). Magnified 38 diameters.

c

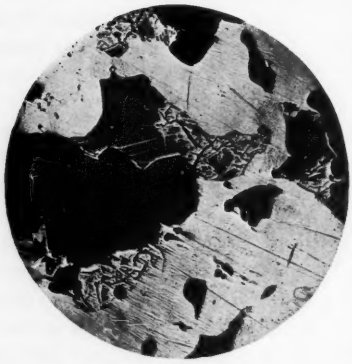


d

FIG. *c*. Bornite (dark) associated with chalcopyrite (light) with mutual boundaries and along gangue veinlets (black). Some spines of secondary chalcopyrite (light) in the bornite. Magnified 60 diameters.

FIG. *d*. Bornite (dark) associated with chalcopyrite (light) with mutual boundaries and along gangue veinlets (black). Magnified 38 diameters.

a



b

FIG. *a*. Bornite (dark) and chalcopyrite (light) with mutual boundaries. Bornite partially altered to secondary chalcopyrite (light). Note shrinkage cracks in lattice patterns. Magnified 60 diameters.

FIG. *b*. Bornite (dark) and chalcopyrite (light) with mutual boundaries. Bornite partially altered to secondary chalcopyrite (light) in lattice patterns. Magnified 60 diameters.

c

d

FIG. *c*. Bornite (dark) partially altered to chalcocite (light) along gangue veinlets (black), with tendency toward lattice patterns. Magnified 38 diameters.

FIG. *d*. Bornite (dark) partially altered to chalcocite (light) with tendency toward lattice patterns. The dark feathery material along the cores of the chalcocite areas is a mixture of oxidized minerals, and small blebs of bornite and chalcopyrite. Gangue, black. For discussion see page 474. Magnified 60 diameters.

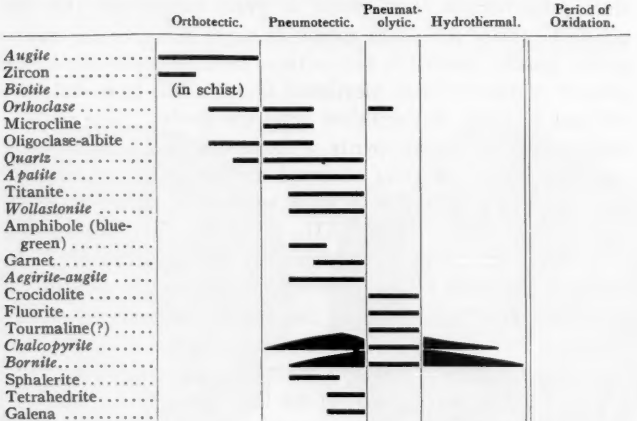
Secondary Minerals.—Chalcocite is not uncommon under the microscope but it is rarely abundant enough to be visible in the hand-specimen. It occurs very sparingly as blebs of indefinite origin in the bornite, but most generally as veinlets or rims about bornite grains, or, less commonly, associated with the chalcopyrite.

Veinlets of chalcocite penetrating the bornite are frequently oriented parallel to several crystallographic directions in the bornite, of which two, three, or four are usually revealed on the polished surface, and form a pattern which has been frequently referred to in other deposits as the lattice ctructure. (Plate XXII., *c.*) It is commonly accepted that the chalcocite in this form is of replacement origin.

Associated with the chalcocite, but more abundantly developed, is chalcopyrite of a second generation, usually in plates penetrating the bornite from cracks or grain boundaries. On the polished surface the plates appear as strips or spines of chalcopyrite, usually oriented in two or three directions, yielding lattice patterns similar to those mentioned above. This later chalcopyrite can be easily distinguished from the earlier. The replacement of bornite by chalcopyrite of the second generation is rarely complete and in all cases observed the outline of the original grain is sharply defined even when against the earlier chalcopyrite. (Plate XXI., *a,* and XXII., *a* and *b.*) The two ages of chalcopyrite are very clearly shown by the replacement of the earlier chalcopyrite by bornite along certain gangue veinlets (as previously described), and by the partial replacement of this bornite in turn by spines of the second generation of chalcopyrite developed along the margins of the same gangue veinlets (Plate XXI., *c*). The development of the later chalcopyrite is accompanied by the formation of numerous small cracks which suggest that the reaction involves a shrinkage in volume. (Plate XXI., *a,* and XXII., *a* and *b*). The distribution of the chalcopyrite and its dependence on the same channel-ways as the chalcocite afford clear evidence that the two minerals were produced by the same agencies. The development of the secondary chalcopyrite

slightly preceded the formation of the chalcocite. It is most probably an iron byproduct of the reactions involved in the alteration of bornite to chalcocite.

In one specimen of bornite partially altered to chalcocite, the chalcocite areas are broken by groups of small feathery veinlets, along or related to which are oxidized products and tiny plates or blebs of chalocyprite and bronite. (Plate XXII., *d*.) In a rough way, the sturcture is parallel to the bornite-chalcocite lattice patterns in the same chalcocite areas, but the bornite blebs usually do not resemble residues. The intervening chalcocite is clean and free from inclusions of any sort. The relations suggest the possibility that the usual reactions of enrichment may have been locally reversed by a concentration of outwardly migrating iron, and that the small amount of chalcopyrite and bornite in this unusual relationship was formed by the replacement of chalcocite.



The tetrahedrite is fairly resistant to the attack of the secondary chalcopyrite. Spines of the latter in bornite were observed to end abruptly against the sharp contact of a tetrahedrite grain. The relations in one polished chip suggest that galena alters more readily than bornite to the later chalcopyrite but the evidence is not entirely convincing.

There is a little covellite with the chalcocite and secondary chalcopyrite but it is almost negligible in amount.

The surface of the ground-water is about 35 feet below the collar of the shaft. Stains of limonite and malachite are common along seams and cracks above it, although the amount of thoroughly oxidized capping is very small and rarely exceeds a few feet in thickness.

DISCUSSION.

The Mineral Sequence.—The minerals observed in the deposit are listed on page 474, and by the diagrams my interpretation of their position in the sequence and their mode of origin is indicated. Only the minerals italicized are important from a quantitative standpoint.

The minerals in the group termed orthotectic[5] are those which are believed to have crystallized from the magma under the usual conditions at a time before the concentration of gases became of controlling importance. The rock-minerals of the normal granite are strictly the only ones which may be included in this group.

In the group termed pneumotectic[5] are placed those minerals which are believed to have been formed directly from the melt, but after conditions had been appreciably modified by the concentration of volatile constituents. The aegirite-augite, amphibole, apatite and wollastonite—the essential minerals of the rock associated with the sulphides—may all be assigned to this group. The first three minerals are known to be products dependent on the presence of the volatile constituents in magmas. The wollastonite occurs with them, apparently of approximately the same age. It is commonly known elsewhere as a mineral of

[5] L. C. Graton and D. H. McLaughlin, "Further Remarks on the Ores of Engels, California," ECON. GEOL., vol. XIII., p. 81, 1918.

contact-metamorphic deposits, probably as a product of gaseous reactions. Hence it is most properly placed in this group. The conditions under which these minerals and the rock which they constitute was formed, are believed to resemble those characteristic of pegmatites. The chalcopyrite and bornite are closely associated with this phase of the rock and probably commenced to form in the pneumotectic period—practically as original though late constituents of rock. In part they appear to have formed directly in the spaces between the earlier crystals; to a lesser extent they developed as partial replacements of the earlier products.

Locally in a few spots in the dike and more generally in the adjoining schist, gaseous action became the dominant process and conditions prevailed which are most properly described as pneumatolytic. The microlitic cavities in the rock associated with the ore offer positive evidence of this action.

The associated minerals—crocidolite and fluorite—should be placed in this group, and the presence of orthoclase and bornite and chalcopyrite in these cavities indicates that they also were formed locally as pneumatolytic products.

The formation of the chalcopyrite, aegirite-augite and the amphibole in the schist are also probably due to pneumatolytic reactions.

The pneumotectic and locally the pneumatolytic products are succeeded by the groups of minerals termed hydrothermal of which epidote, sericite, and calcite are the chief members. The association of epidote and sericite with some of the bornite indicates that the sulphide probably continued to form under hydrothermal conditions. The calcite is later than the sericite or chlorite and is probably the closing product of the mineralizing processes.

The whole process of the mineralization is believed to be an unbroken sequence from the initial orthotectic conditions of the magma to the final feeble hydrothermal effects. The magma is believed to have been abnormally rich in the volatile and rarer constituents—probably as an initial concentration or differentia-

tion from the main monzonitic mass—and consequently in the course of its crystallization pneumotectic and locally pneumatolytic conditions became of importance, which with decreasing temperature gradually gave way to relatively mild hydrothermal phases.

Speculations Concerning the Wollastonite.—The unusual occurrence of wollastonite as a constituent of an igneous rock, however, suggests that in this case peculiar conditions probably existed which may very possibly have been of direct importance in the concentration of the sulphides. Bastin and Hill believe that the high content of CaO in the magma is due to the reaction of the melt on calcareous country rock. The sharp boundaries between the intruded material and the included schist fragments exclude the possibility of any notable material having been absorbed from the wall-rocks at the horizons exposed and consequently they concluded after weighing various possibilities that the magma probably encountered calcareous rocks at depth.

This hypothesis with the aid of the theory advanced by R. A. Daly[6] for the origin of alkaline rocks suggests a mode of origin for the deposit which is in harmony with the evidence as presented and interpreted on the preceding pages. According to Daly, alkaline rocks are the acid pole of the differentiate of a syntectic formed by the reaction between a basic magma and a calcareous rock. The increased concentration of CaO is believed to result in the formation of the comparatively dense lime-iron magnesian silicates, which tend to concentrate toward the lower portions of the magma, leaving the remaining material relatively richer in the alkalies. In this case, starting with a monzonitic rather than an extremely basic magma, an excess of CaO might conceivably separate as the simple silicate, wollastonite ($CaSiO_3$), which would have little tendency to settle away from the acid pole, as its specific gravity of 2.8 (at normal temperatures) is but little greater than that of a monzonitic rock. The importance of resurgent carbon dioxide is emphasized by Daly as a condition aiding the differentiation of the magma, and evidence is given illus-

[6] R. A. Daly, "Igneous Rocks and their Origin," New York, 1914, p. 430.

trating the manner in which the alkaline elements are transported by this gas. In the Evergreen deposit, the strong development of calcite indicates that at least in their later stages, the emanations which formed, the ores were rich in carbon dioxide. It is possible that the resurgent gas may have been an important factor in the concentration of the sulphides. This possible mechanism, although of course largely speculative in this particular case, is of serious interest in that it offers a common explanation for the alkaline tendencies of the rock, the presence of wollastonite, and the numerous relations indicating the importance of gases in the formation of the deposit.

Origin of the Chalcocite.—The chalcocite and the associated chalcopyrite are most probably of secondary origin. Although the amount of oxidation is slight, it is entirely sufficient to have furnished the very small quantity of copper necessary to have formed the thin rims or veinlets of chalcocite. The character of the replacement of bornite and the association between the chalcocite and the spines of chalcopyrite is very similar indeed to the conditions found in other ore-bodies in connection with chalcocite of known secondary origin and there is no reason for believing this case to be exceptional. A. F. Rogers,[7] in an article on secondary sulphide enrichment, suggests an origin by ascending solutions for the chalcocite at the Evergreen Mine, and publishes a photograph to support this view. It is true that there is a small amount of chalcocite in blebs in the bornite which is difficult to interpret as an ordinary replacement of the bornite, and which is possibly of an earlier age than the chalcocite forming the veinlets and rims. In one or two cases blebs of chalcocite and tetrahedrite in the bornite were observed which showed a faint tendency toward the graphic structure. If limited to the chalcocite in these rather indefinite forms, which surely constitute less than five per cent. of the chalcocite present, Rogers' suggestion carries weight and can not be disregarded. There is nothing

[7] A. F. Rogers, "Secondary Sulphide Enrichment of Copper Ores with Special Reference to Microscopic Study," *Min. and Sci. Press,* October 31, 1914, p. 686.

in the evidence to eliminate the possibility that this small portion of the chalcocite is primary, but it is fairly certain that the larger part of the chalcocite and the associated chalcopyrite which replaces the bornite is due to the action of descending surface waters. Bastin in a later article[8] sees no reason for attributing the chalcocite to ascending solutions and prefers the commoner explanation for it.

CONCLUSIONS.

The ore-deposit at the Evergreen Mine is believed to be the product of the differentiation of apophyses of a monzonitic stock brought about largely by gaseous action. The sulphides are regarded as original constituents of the rock formed under pneumotectic conditions, but also in minor part as products of pneumatolytic and hydrothermal conditions. The presence of the wollastonite leads to the speculation that possibly resurgent gases played an important rôle in the differentiation of the rock and the concentration of the sulphides. The small amount of chalcocite, developed as a replacement of bornite, is believed to be of secondary origin.

[8] E. S. Bastin, "The Ore-deposits of Gilpin Co., Colorado," ECON. GEOL., vol. 10, 1915, p. 276.

GEOLOGIC FACTORS IN OIL PROSPECTING.

FREDERIC H. LAHEE.

CLASSIFICATION OF GEOLOGIC WORK.

Geologic work in connection with the petroleum industry may be classified under the following heads: (1) The exploration or prospecting of unproved territory; (2) the detailed mapping of areas that are thought to be promising, often on account of nearness to producing wells; (3) the choice of sites for wells; and, (4) recommendations concerning the depths of water-bearing strata, the depths of oil or gas sands, the source of unexpected water, the recognition of rock types, and so on, in wells which are being drilled. The present article refers chiefly to the first of these classes of work.

GEOLOGIC FACTORS IN OIL PROSPECTING.

The exploration of unproved territory may be undertaken to ascertain the prospects in a region not yet known to have any possibilities of oil; to investigate a district underlain by a formation which is productive at some other distant locality; to extend the limits of a producing field; or to examine an area believed to have favorable indications such as oil showings in water wells, oil or gas seepages, or wildcat oil or gas wells. For this kind of work every available source of information is consulted. The literature especially is studied. Generally a reconnaissance survey is made in the field and all possible facts are observed and recorded regarding rocks, stratigraphic and structural conditions, springs, seepages, and other features which may be of practical value. The logs of water wells and wildcat oil and gas wells, when reasonably well kept, may be of much assistance. The geologist then correlates these data, estimates their significance, and draws his conclusions as to the prospects for discovering oil

in commercial quantities in the area. Obviously the geologic factors which govern his conclusions are of very great importance. These factors may be enumerated as follows: (1) Classification of the rock formation, (2) thickness percentage of rock types, (3) relation to original shore lines, (4) reservoir or sand conditions, (5) structural conditions, (6) depth to possible oil-bearing horizons, (7) the carbon ratio. These will be discussed in the order named.

CLASSIFICATION OF THE ROCK FORMATION.

According to the most commonly accepted view of the origin of petroleum and natural gas, these substances have been derived by certain processes from plant and animal remains which were buried in sediments at the time of deposition. In a majority of the producing fields of to-day the petroliferous sediments are marine, or the oil or gas has migrated from marine[1] beds. This statement is not intended to imply, however, that in some instances fresh-water sediments may not have been the primary source. The old idea of an igneous origin for petroleum is held by few, if any, modern geologists.

The significance of these facts is that (1) an area underlain by massive igneous rocks, which may be actually exposed or only thinly covered, may be condemned as almost certainly unfavorable for oil; (2) an area underlain by sedimentary rocks will bear further investigation; and (3) the chances may be regarded as very much better in the case of marine strata than in that of fresh-water strata.

THICKNESS PERCENTAGE OF ROCK TYPES.

Oil-bearing formations usually consist of alternating beds of sand and sandstone, clay or shale, and limestone, laid one above another. Estimates of the comparative total thicknesses of these rock types have shown that the average proportion of sandstones to shales plus limestones is between 10 per cent. and 20 per cent.

[1] The term is here used to include the littoral facies.

of the whole formation. Ordinarily the combined thickness of the shales is twice or more than twice that of the limestones.

The shales are supposed to have held a rich content of organic matter from which the petroleum and natural gas originated and migrated into the sands. The limestones, too, may have contributed some of the products. We may conclude, then, that in an undeveloped region a series of marine strata with a small thickness percentage of sandstone and a large thickness percentage of shale, and perhaps some limestone, offers the most favorable chances for the presence of oil, other things being equal. If sandstone preponderates, the shales may be too thin to yield commercial quantities, and whatever oil or gas may have formed is likely to have escaped through the great bulk of sandstones. On the other hand, thick limestone formations with little shale and no or little sandstone are less favorable than a great thickness of shales, although more so than a great thickness of sandstones.

RELATION TO ORIGINAL SHORE LINES.

If we study a coast of today, we find that sand predominates near the shore, mud farther seaward, and still farther away from the land, where the water is relatively clear, certain kinds of limy deposits occur. These three phases, the sandy, the muddy, and the limy, extend along the coast in roughly parallel belts. This mode of distribution has many exceptions and irregularities, but in a broad way it generally holds true.

Without doubt somewhat similar conditions existed when the older marine sedimentary formations were laid down. We should expect to find the intermediate shallow-water or shale phase, representing the hardened muds, occupying a zone parallel to the ancient shore line which, to be sure, may have been in a very different position from any modern shore lines; and this zone would lie between the sandstone or shore phase and the limestone or deeper water phase.

On account of successive transgressions and regressions of the sea and because of variations in the conditions of transportation of land débris to the shore, during the period of deposition of a

formation or a series of formations, the three zones of one time were not necessarily superimposed upon the corresponding three zones of an earlier date. As sedimentation progressed the shore line, and with it the sandy, muddy and limy belts, alternately advanced landward or retreated seaward, thus producing a stratified series in which the muds on their landward side interwedged with the sands and on their seaward side interwedged with the limy materials. By reference to Fig. 31 it will be seen that the most favorable part of such a formation, with a large thickness percentage of mud (or shale), lies between the lines *cd* and *ef*. Seaward of *ef* limestones begin to predominate and landward of *cd* sandstones predominate. In Fig. 31, although the zones moved

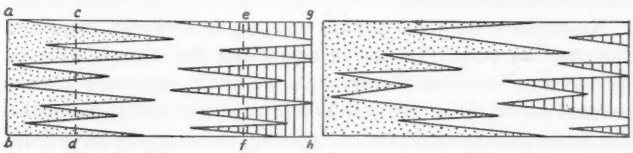


FIG. 31. FIG. 32.

FIGS. 31 and 32. Cross-sections of deposits laid down during successive transgressions and regressions of the sea. Land, left; sea to right; sand, stippled; mud, blank; lime, vertically ruled. Vertical scale exaggerated.

now landward and now seaward, the average position of the sand, mud and lime phases remained constant; that is, the lines *ab, cd, ef,* and *gh* are vertical. Fig. 32 illustrates a case in which the average position itself migrated landward during the deposition of the lower beds and seaward in the subsequent sedimentation. Variations of this kind are natural and for this reason the three phases in a sedimentary series cannot always be definitely located; but if, by a study of the regional geology, we can learn the general relations of the land and sea at the time when a certain formation was being deposited, we can hazard an opinion as to the probable position and distribution of the more favorable shaly phase within this formation.

RESERVOIR OR SAND CONDITIONS.

The ideal reservoir for the accumulation of oil is a porous sand which is uniform in its character, and which lies between two impervious retaining beds, also uniform in character. Such conditions are seldom met. From the nature of their origin, strata are likely to vary laterally, that is, along and within the same beds. Sands may become finer and therefore less permeable by oil, and they may grade into shales, or they may grow thinner and finally pinch out. Or, again, because of unequal degrees of cementation, they may be "open" in one locality and "closed" or "tight" in another. Shales and clays which in one place are impervious may become so porous elsewhere that they no longer serve as retaining walls.

Reservoir conditions of this sort are exceedingly important for they are potent factors in controlling the accumulation of petroleum. Many of the dry holes in producing pools are accounted for by them. It would be fortunate indeed if the geologist could predict local sand variations, but unhappily he is quite unable to do so. Merely in a general way he can say that probably this formation will be characterized by comparatively uniform bedding and that one by very irregular stratification. The chances of success will be greater where the bedding is regular.

STRUCTURAL CONDITIONS.

The term *structure,* used in its broadest sense, refers to the arrangement, mutual relations, and form of definite rock masses, as these are dependent on stratification, unconformity, folding, faulting, igneous intrusion, etc. The thinning or wedging out of strata, already mentioned, is properly a structural condition, although it was more conveniently treated here under sand conditions. In the present section we shall consider only unconformity and folding, omitting the more special cases of faults and igneous intrusive masses.

1. *Regional Folding and Warping.*—Structural conditions due to bending, warping, or folding, may be classified as local and

regional. Local structures may be a hundred square miles or less in area, whereas regional structures may extend over many hundreds or thousands of square miles. Local structures are often carefully mapped to determine the most promising acreage for leasing or the best sites for wells, but before any field is thus studied in detail its relations to the large regional structures should be understood.

These regional structures are characteristic of the lithosphere. The broad downwarped basins and troughs are called geosynclines and the corresponding uplifts are geanticlines. Examples are the Black Hills uplift, the Cincinnati geanticline, the Arbuckle Mountains uplift, the Central Mineral Region of Texas, the Sabine uplift in Louisiana, and the Rio Grande embayment.

The bearing of such regional structures on the question of oil accumulation may be appreciated if we accept the anticlinal principle. According to this principle, if oil, water and gas are free to migrate within the open spaces of a rock body which is essentially closed to their escape, they will accumulate in the order of their specific gravities with the lightest at the top. Hence, theoretically, in a series of anticlines and synclines, gas will be at the crests of the anticlines, water in the troughs of the synclines, and oil on the limbs of the folds. If there is little free or undissolved gas, the oil will be high up toward or at the anticlinal crests, and the water below it. If there is no water in the sand, oil will be in the synclinal troughs and gas above the oil.[2] Since experience has shown that dry sands are the exception, recommendations in reference to untested regions are based on the supposition that the prospective formation is water-bearing.

Provided we assume that water, oil and gas are present and have been free to migrate within the strata, regional structure is the primary control and local structures are secondary.[3] Local

[2] The reader should observe that the occurrence of oil in a dry sand in the synclines is still governed by the anticlinal principle of accumulation. That a "dry" sand should actually be water-containing and not water-yielding, and that the oil should come from the synclines in such a sand, is hardly conceivable.

[3] This and the succeeding statements are made without reference to varying sand conditions which might distinctly modify the relations.

anticlines on broad uplifts have a double chance of success. Even the local synclines on geanticlines may yield production under certain conditions, in spite of the fact that the sand as a whole may be wet (*i. e.*, water-bearing). Local anticlines in geosynclines may carry oil where the local structure is relatively strong and the regional structure is relatively weak, but if the local structures are weak, these anticlines may contain water.

As a general hypothesis, then, the sides and crests of broad regional arches are to be regarded as more favorable than the lower portions of regional basins and troughs in formations which are promising in other respects.

2. *Unconformity.*—Unconformable relations, which are not uncommonly associated with oil-bearing formations, may seriously affect the prospects in a region. Fig. 33 shows a case in

FIG. 33. Cross-section of an older formation, *A*, partly removed by erosion and covered by a younger series, *B*. The black band represents an oil-bearing sand. Vertical scale exaggerated.

which a petroliferous formation has been folded, eroded, and then overlain by a non-petroliferous series. To the left of *ab* and to the right of *gh* oil might be obtained from good structures (not represented) in series A. Between *ab* and *cd*, and between

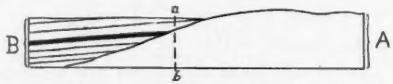


FIG. 34. Cross-section of a younger series of beds, *B*, pinching out by overlap against an older formation, *A*. The black band represents an oil-bearing sand. Vertical scale exaggerated.

ef and *gh*, some oil might be discovered in small pools in series B into which it migrated from A after the deposition of B. Oil would not be expected in either series between *cd* and *ef*.

In Fig. 34 the black layer, representing an oil-bearing horizon in series B, pinches out by overlap against the older formation, A. To the right of *ab* it never was deposited and consequently the prospects here are nil. On the other hand, favorable structures might yield oil to the left of *ab*. This condition is easy enough to

FIG. 35. Cross-section of two formations, like those in Fig. 4, partly eroded and covered by a third, still younger series, *C*. Vertical scale exaggerated.

recognize if the two formations are exposed, but if, as in Fig. 35 a third series, C, covers both A and B, the problem becomes much more difficult to solve. As before, the chances to the right of *ab* are very poor, but to the left they may be good.

The question sometimes arises as to the probable relations of structures in two series of strata separated from one another by an unconformity. Observations have shown that regions which have been affected by uplift or depression once may have undergone the same kind of movement more than once, and that consequently a regional arch in an upper series may be a more pronounced regional arch in a lower stratified series which unconformably underlies the upper group.

The same statement may be made with reference to the regional basins. However, it is not necessarily true that the major structures in a lower series are present in any degree in an unconformably overlying series. (See Fig. 33.)

DEPTH TO POSSIBLE OIL-BEARING HORIZONS.

By observations on dip and strike and by paying due attention to surface elevations, the geologist can estimate the probable depth of a horizon which is thought to be oil-bearing. Very slight depths are regarded as unpromising because any oil that may have been present may have escaped. Great depths are unfavorable because of the high cost of drilling deep wells. What is "shallow" or what is "deep," from the practical standpoint,

depends on the nature of the formation, the type of structure and so on. Ordinarily depths less than 500 feet or, in some regions, 1,000 feet, and greater than 4,000 or 4,500 feet are unfavorable.

THE FIXED CARBON RATIO.

When stratified rocks are tilted and folded they undergo alterations which are induced by the compressional forces, assisted by heat and moisture. The more intensely they are folded and the longer they are subjected to the forces which accomplish the folding, the greater these alterations become. Coal and petroleum, both of which may occur in the same geologic series, belong to two classes of substances which are readily modified by the processes associated with rock compression.

The effect on coal is to drive off the volatile constituents and thereby to increase the relative proportion of fixed carbon remaining. The ratio of the fixed carbon to the sum of the fixed carbon and the volatile hydrocarbons in any coal is termed the fixed carbon ratio of that coal. Obviously this ratio will increase in value the more the coal has been altered in the manner just indicated.

The change in petroleum compounds has not yet been satisfactorily explained; but we know that it is progressive and that certain values of the fixed carbon ratio in coal roughly correspond to certain values in the gravity of oil present in the same formation. The fixed carbon ratio of the coal and the gravity of the oil, in degrees Beaumé, increase together. When the fixed carbon ratio approaches a certain limit, observed to be between 65 per cent. and 70 per cent., the chances of finding commercial quantities of oil, even in a formation which is productive elsewhere, become greatly reduced, and beyond this limit the chances are practically negative.[4] As a rule we may assume (1) that the

[4] The importance of the fixed carbon ratio as a factor in petroleum exploration was first suggested by Dr. David White. See "Late Theories Regarding the Origin of Oil," Geological Society of America, Bull. 28, pp. 727–734, 1917.

To Mr. M. L. Fuller is due a large share of credit for having early appreciated and applied both the factor of the fixed carbon ratio and that of regional, as contrasted with local, structure, in investigations for petroleum.

fixed carbon ratio very gradually increases downward in a thick conformable series, and (2) that, with reference to two unconformably related formations, the fixed carbon ratio is greater in the underlying formation than in the overlying formation.

THE PROBLEM OUTLINED.

The factors which have been mentioned are not all, but they are important. They relate to conditions underground, sometimes deep below the surface, and often the deductions in unproved territory must be founded on data which can be obtained only at the outcrop of beds far outside the specific area under investigation. Great care must therefore be exercised in studying and weighing their significance.

Few of the factors can be estimated with precision. The classification of the rock and the fixed carbon ratio (provided there is coal or carbonaceous shale in the formation) can usually be determined with some degree of certainty, but the remaining factors are much more difficult to gauge. The geologist's aim should be to settle as soon as possible whether or not an area gives indications of promise. Consequently the factors should be considered in what we may call the order of decreasing certainty of determination. The following order is suggested, the problem being outlined in the form of questions:

A. Is the area underlain by massive igneous rocks, exposed or at shallow depth?

B. If the area is underlain probably by a considerable thickness of sedimentary rocks, particularly marine sedimentary rocks:

1. Is the fixed carbon ratio near or above the observed safety limit?

2. If the fixed carbon ratio is within the safety limit:

a. Is the regional structure synclinal or anticlinal?

b. What are the probable upper and lower limits of depth to the supposed oil-bearing formation, *i. e.*, within what limits of depth below the surface is it thought oil-bearing strata may occur?

c. Is there any possibility that the supposed underlying oil-bearing formation is cut out by unconformity or has pinched out by overlap?

d. What are the probable relations to original shore lines, and what, roughly, are the probable thickness percentages of rock types within the formation beneath the area in question?

e. Can anything be said as to probable sand or reservoir conditions in the formation?

In closing we may add that the main question always to be answered is, Are there, geologically speaking, any indications or possibilities of finding oil in the district, and, if so, are these such as to justify favorable recommendations under the existing conditions of transportation, fuel, water, depth to oil sands, and prices asked?

DALLAS, TEXAS.

DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

MAGNETIC AND NON-MAGNETIC CHROME.

Sir:—Dr. Singewald's paper[1] is an extremely interesting and suggestive contribution to the literature of chromite. The results of analyses, as shown by diagrams, exhibit the great range in composition that we have learned to expect in this exceedingly variable member of the spinel group. The separate analyses of the magnetic and non-magnetic fractions are especially instructive, and it is to be hoped that this paper may inspire other investigations of a similar nature upon ores from many different localities and widely separated regions.

The wide range in chromic oxide content, on which so directly depends the value of the mineral for the chemical industry, is clearly and impressively brought out. In this connection I would also call attention to another point of economic importance for which Dr. Singewald's data furnish the basis. For chemical purposes, as is well known, an ore containing 50 per cent. Cr_2O_3 or higher is demanded; on the other hand, ores that run much lower in chromic oxide may be successfully smelted for ferrochrome, but for this purpose the metallic chromium-iron ratio should not fall below about 2:1. Dr. Singewald's analyses show, however, as nearly as may be scaled from the diagram, that even a non-

[1] Joseph T. Singewald, Jr., "Maryland Sand Chrome Ore," ECON. GEOL., vol. XIV., pp. 189–199, 1919.

magnetic chromite may run so high in iron as to pull down this ratio to about 1 : 1.

It is highly desirable that studies along this line be extended to close fractionation by means of electromagnets, and that massive ores be examined by metallographic methods in connection with crushing and fractional separation. It would be both interesting and important to determine, for example, whether a magnetic concentration method might be so designed as to draw the line at just the right point for smelting ore, or whether, with varying proportions of FeO and Fe_2O_3, this would be impossible. Practical questions of this sort would quickly find at least a partial answer in the accumulation of data from many localities.

Dr. Singewald's data, somewhat rearranged, are presented in the following tables, which show some interesting comparisons and contrasts between the various magnetic and non-magnetic fractions.

MOLECULAR CONSTITUTION OF MAGNETIC AND NONMAGNETIC PORTIONS OF MARYLAND SAND CHROME.

	Nonmag.		Magnetic.		Means.	
	I.	IV.	I.	IV.	I.	IV.
$MgO.Al_2O_3$	19	19	16	0	18	10
$FeO.Al_2O_3$	20	45	4	8	12	26
$FeO.Cr_2O_3$	52	10	31	3	41	7
$FeO.Fe_2O_3$	9	26	49	89	29	57

Or, collecting the molecules containing Al_2O_3, etc., the same data may be given as follows:

	Nonmag.		Magnetic.		Means.	
	I.	IV.	I.	IV.	I.	IV.
Al_2O_3 mols.	39	64	20	8	30	36
Cr_2O_3 mols.	52	10	31	3	41	7
Fe_2O_3 mols.	9	26	49	89	29	57
FeO mols.	81	81	84	100	82	90

Concerning some of Dr. Singewald's conclusions there is room, perhaps, for difference of opinion. The arithmetic mean of the

magnetic and non-magnetic parts of sample IV. is very high in iron, containing 57 per cent. of molecules with ferric oxide and 90 per cent. with ferrous. A mineral of this composition would in all probability be magnetic, since it would be higher in both ferrous and ferric molecules than the magnetic portion of sample I. On the other hand, while a mineral corresponding to the mean of sample I., with only 29 per cent. of ferric molecules and 82 per cent. ferrous, "*may be* highly magnetic," as the author supposes; this seems to be merely a matter of opinion, and of very doubtful opinion it seems to me, since such a mineral would be almost identical in both these constituents with the non-magnetic portion of sample IV.; hence to set it down in the table as positively magnetic, without question or qualification, is misleading.

As an attempt to estimate the probabilities from the limited data, it *may be* permissible to say that "a spinel molecule carrying an equivalent of only 29 per cent. magnetite *may be* highly magnetic if chromic oxide is in excess of alumina," and possibly even to assert that "these figures indicate that a chromite containing no alumina *might be* highly magnetic if it contains an equivalent of less than 25 per cent. magnetite" (italics mine); yet, in the absence of an adequate experimental basis for such conclusions, it would seem a safer course to stick to the determined facts and keep these figures up in the forties until, by means of fractional separation or otherwise, a magnetic variety with a lower magnetite content is actually found.

In demonstrating the existence of (1) a magnetic ore containing less than 50 per cent. magnetite molecules, and yet sufficiently high in chromic oxide to come within the range of commercial ores, and (2) a non-magnetic spinel which closely resembles good chrome ore, but falls below 7 per cent. in chromic oxide, Dr. Singewald has made a valuable contribution to our knowledge of these ores and provided a substantial basis for his cautions to miners and prospectors against mistaking the one for valuable chrome and rejecting the other as only magnetic iron ore.

Dr. Singewald's final and, from the practical viewpoint, most important conclusion, therefore, as to the inadequacy of simple

field tests for chrome ore and the necessity of checking such observations by chemical analyses, is abundantly substantiated and cannot be too strongly emphasized.

Permit me to add here a plea for the separate determination of ferrous and ferric oxides. This is highly desirable in all analyses of scientific value and is especially needful in a comparative study of magnetic and non-magnetic varieties. In the case of chromite, for example, some of the protoxide is very commonly combined with magnesia and silica in the form of olivine or serpentine. This is particularly true of the massive ores, and hence without a separate determination of the oxides the proportion of magnetite molecules that enters into the composition of the chromite cannot be calculated, except on the basis of assumptions that may involve considerable errors.

I would also plead for the publication of analytical data in full. While values may be measured approximately on a diagram, the figures thus obtained cannot well be used, for example, in a tabulation of analyses for comparative study. Diagrams are valuable aids in visualizing the results, and their more frequent use with analyses would be highly commendable, but they are hardly a satisfactory substitute for the actual figures.

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REVIEW

The Mineral Deposits of South America. By BENJAMIN L. MILLER and JOSEPH T. SINGEWALD. New York, McGraw-Hill Book Co., 1919.

The book contains observations made by the authors as a result of a trip through South America in 1915, and information regarding mineral deposits gathered from all sources. Its particular value lies in the fact that it is a summary of the available data on the economic geology of the continent.

The first chapter deals with the economic geology of South America. The physiographic provinces are first briefly outlined. Then follows a very short summary of the geological development of the continent. The relation of mineral deposits to the geological formations in them is sketched and the chapter closes with short sections on the history of the mineral industry, the relation of mining to other industries and the future development of the mineral resources, and a bibliography.

The remaining chapters describe the mineral deposits of the different countries, in alphabetical order of countries. Each chapter opens with a short résumé of mineral production, followed by a sketch of the topographic and geologic features and then a description of the mineral deposits under the heads of the different minerals and more detailed descriptions of the important districts. Each chapter closes with a full bibliography.

The chapter on Argentina treats briefly the numerous small gold-producing districts, the copper deposits, minor districts producing lead, iron, manganese and cobalt. The most important metalliferous regions, the Famatina district and the tin and tungsten deposits of San Luis and Códoba, are described at more length.

The Famatina deposits consist of veins in Paleozoic sediments and igneous rocks; the copper veins are the most important and occur in slate near the contact of granitic intrusives. The gangue is quartz, barite and calcite and the important ore minerals enargite, famatinite, tetrahedrite and chalcopyrite. Chalcopyrite, bornite, covellite and chalcocite occur in some deposits.

The tungsten deposits of the region between San Luis and Córdoba and the tin deposits of La Rioja are interesting mainly from the fact that they present evidence of a period of tin metallization of Paleozoic

age, as compared with the late Tertiary of the Bolivian tin deposits. The wolframite and cassiterite occur in veins genetically associated with the pegmatitic phase of post-Silurian granites. In places, subordinate scheelite together with various sulphides also occurs. The principal gangue material is quartz. Tourmaline is present in the most important veins. Mica, fluorite and apatite also occur.

The principal non-metallic product of the Argentine is petroleum. A small production has been made, but the vast petroliferous area, estimated at 8,000 square miles, is as yet practically unproved. The petroliferous horizons are of Triassic, Jurassic, Cretaceous and Eocene age.

In the description of Bolivia the authors rely largely on their own observations, and this chapter is consequently more interesting.

In the Coro-Coro district native copper is an important ore mineral in beds of sandstone in close association with a fault plane. Although no igneous rocks are exposed in the immediate vicinity of the mines a probable genetic relation with the dioritic rocks in the neighborhood is suggested. The age of mineralization is late Tertiary.

The tin-silver-bismuth-tungsten deposits form a metallogenic province of limited extent, occupying the Bolivian portion of the Cordillera Real. The peculiar features of the deposits are the comparative rarity of the usual pneumatolytic minerals, the presence in the original ore of stanniferous pyrite, and a large variety of sulphides, including stannite and complex stanniferous sulphides. A marked enrichment in silver yielded the famous bonanzas of silver sulphides and native silver. The oxidized zone consists largely of an intimate mixture of limonite and cassiterite. Mechanical enrichment of the cassiterite contained in the stanniferous pyrite, in the zone of oxidation has been of importance. The occurrence of wood tin indicates some solution and deposition as well, although this is not considered important.

The deposits are associated with silicic intrusives, usually porphyritic in texture. The determination of a Pliocene age for these deposits is of particular interest. The Argentine tin and tungsten deposits, however, belong to a Paleozoic metallogenic epoch.

In the chapter on Brazil the gold mines of Minas Geraes, the iron ores, the Lafayette manganese deposit and the diamond deposits are described in most detail.

At the Morro Velho mine the persistence of a single ore body to a vertical depth of over 6,000 feet is of especial interest. The average width is 10 to 12 feet and stope length 600 to 1,000 feet, and the principal ore minerals are pyrrhotite, pyrite, and arsenopyrite in a gangue of quartz and carbonates. The tenor has held in depth, and the limit of work in depth will probably be determined by the increase in costs of cooling, the average rate of increase in temperature being 1° F. for

each 125 feet increase in depth. The lodes of the Passagem mine have been formed by the replacement of gently dipping quartzite at the contact with itabirite.

As befits their importance, the Brazilian iron ores receive detailed treatment. The enormous tonnage of available reserves will surprise many readers, but recent estimates surpass the figures given in this book. The deposits have been studied by a group of able American and foreign geologists and the results are well summarized by the authors. The orignial or bedded ores are of pre-Cambrian age and assumed their present characteristics through regional metamorphism in pre-Cambrian time. The authors favor the hypothesis of origin proposed by Harder and Chamberlain which considers that the ore beds represent original sedimentary strata, and that the iron was precipitated in the form of iron hydroxide.

The manganese deposits of the Miguel Burnier district probably represent replacements of limestone lenses in a schist-itabirite series. The Lafayette or Queluz district is now the chief manganese producer of Brazil. The ores occur in the Archean basement complex consisting of gneiss and schist intruded by granite which underlies the iron-bearing series. The manganese deposits occur as elongated masses and represent residual products of decomposition of a rock made up of manganese carbonates and silicates. Descriptions of other manganese deposits of Brazil, notably those of Matto Grosso and Bahia, are also given.

Brazil practically supplies the world's demand for monazite. Derby has shown the almost universal presence of monazite in the muscovite granites of the country, so naturally monazite placers are widely distributed. Up to the present the beach placers of Bahia and Espiritu Santo have furnished almost the entire production. The stream placers, however, contain the larger supply. It is estimated that the beach sands will yield from 15,000 to 20,000 tons of monazite concentrates while the river placers thus far known will yield ten times the amount. The world's consumption amounts to about 3,000 tons per year.

In Chile, copper is the principal metal produced. The mines of the arid region are characterized by great depth of oxidation and by a great variety of oxidized copper minerals. Only in Chile do such minerals as brochanite, atacamite, chalcanthite and kröhnkite form an essential part of the ore. Secondary sulphide minerals are also of importance and in places the zone of mixed oxide and sulphide ores reaches great thickness, the uneven distribution being due to the concentration of the scanty supply of downward flowing water along favorable channels.

At Chuquicamata five zones are recognized; first, a leached zone of variable thickness; second, the so-called brochantite zone in which

the shattered rock is filled with stringers of soluble copper minerals such as brochantite, atacamite, chalcanthite, kröhnkite, cuprite, and some native copper. This zone has a maximum thickness of 360 feet. Third, a zone of mixed sulphides and oxides. Fourth, a zone containing secondary sulphides, mainly chalcocite and covellite. Fifth, the primary ore composed of pyrite, chalcopyrite, enargite and bornite. The known and probable reserves are estimated to contain 700,000,000 tons of ore averaging 2.12 per cent. copper, of which about half is oxidized ore.

The nitrate deposits are disconnected areas within a narrow zone in northern Chile, extending a distance of 450 miles. They lie near the western margin of the longitudinal valley and on the flanks of the Coast Mountains. They are limited to the lower-lying portion of this valley, but do not occupy the lowest depressions, which are salt-encrusted areas. The principal nitrate-bearing bed is usually covered by a few feet of barren or low grade material, and although a maximum of 6 feet is reached, the average thickness is about a foot. Commonly material containing as much as 17 per cent. nitrate is worked.

Various theories of origin have been proposed. The principal ones are: oxidation of seaweed along a former coast line, reaction of saline waters upon guano deposits, the action of nitrifying bacteria on ancient vegetable matter, and fixation of atmospheric nitrogen through electrical activity. The authors believe that the deposits resulted from the accumulation by means of evaporation of the minute nitrate content of the underground waters, where they come to the surface on the ascending limb of an artesian circulation. Capillarity effectively feeds the shallow ground waters of the region to the atmosphere and the soluble salts accumulate between the surface and ground water level. The nitrate, owing to its deliquescent nature, tends to accumulate around the saline basins.

Reserves of nitrate in the small portion of the fields which have been carefully surveyed, are estimated to be 240,300,000 tons; the total probably exceeds 600,000,000 tons and the maximum yearly production has been less than 3,000,000 tons. Iodine is obtained as a by-product of the nitrate fields and potash deposits occur in some of the saline areas. Of these the best known is the Pintados Salar. The most important borax deposits are in basins which receive the drainage from the recent volcanoes of the region.

Chile is more fortunate than other South American countries in possessing coal reserves of importance favorably situated for mining. The coal is of Tertiary age and is mined chiefly in the south-central provinces. At present the Chilean coal production furnishes about half the domestic requirements.

Gold and platinum are at present the principal mineral products of

Colombia. The primary gold deposits are confined to the pre-Cretaceous metamorphic rocks and the granular intrusive rocks which cut them. The majority of the mines are in the Cordillera Central. The principal placer regions are those of Antioquia and Chocó. Dredging operations on Nechi River have given yields of 31 to 49 cents per cubic yard. Platinum occurs in the gold placers of the Chocó and forms from a small percentage to over half the metallic content of the placers.

The Muzo emerald deposits have been idle since 1912. The emeralds are found in calcite veins in a series of thin beds of shale and limestone. Pogue, whose description the authors follow, shows that they are of pneumatolytic origin.

The Zaruma gold district is the only important metal-producing region in Ecuador. Here veins of quartz and calcite carrying auriferous sulphides occur along fault planes in a diorite or andesite. Oil is known near the coast, west of Guayaquil. The region is probably the northward extension of the Peruvian fields.

Placer gold is the principal mineral product of the Guianas, practically all the rivers having proved auriferous. Lode mining is not of much importance and some geologists consider that much of the gold has been derived from basic intrusives. Diamonds have been found in places in the gold placers, particularly in British Guiana. Large deposits of high grade bauxite are now being developed.

Paraguay appears to have no mineral deposits of present importance. Iron and manganese deposits exist and may be developed when transportation is improved. Kaolin is also of possible future importance.

Most of the important mineral districts of Peru were visited by the authors and are described in detail.

The ore bodies of Cerro de Pasco occur as replacements in rhyolitic agglomerates and tuffs. The oxidized ores worked in the early days were rich in silver, but practically barren of copper. Besides large masses of pyritic ore too low grade to be worked at present, the sulphide ore consists of a mixture of pyrite with enargite and famatinite. In the deeper workings increasing amounts of galena and sphalerite are found. Much of the enargite and famatinite has the appearance of secondary sulphide ore found within the lean pyritic material.

The Morococha district has a great variety of ores. The veins in the igneous rocks are characterized by abundance of enargite and the replacement bodies in limestone are characterized by chalcopyrite. Tetrahedrite is common to both types.

The veins of the Casapalca district contain pyrite and tetrahedrite in a quartz gangue. The principal vein has already been developed through a vertical distance of 2,700 feet.

The ore bodies of the Colquijirca silver mine, near Cerro de Pasco,

consist of replacements of folded limestone by silica and pyrite, associated with galena and pyrite. The oxidized ores, now nearly exhausted, are remarkable for the magnificent specimens of native silver.

The Minasragra deposit, although small in extent, has furnished about 80 per cent. of the world's demand for vanadium. The ore body is a lens-shaped mass having a length of about 300 feet and a maximum width of 30 feet, the long diameter being parallel to the enclosing shales but with steeper dip. It is made up essentially of the hydrocarbons, quisqueite and coke and the sulphide of vanadium, patronite. Small pockets of pyrite are present and in places also bravoite, a nickeliferous iron sulphide. Oxidation has resulted in the formation of a number of vanadate minerals. The authors regard the ore body as a result of the replacement of the slates.

Other Peruvian ore deposits are treated in less detail. A small production of quicksilver is still derived from the famous Huancavelica deposits. The tungsten deposits in the department of Ancachs and Libertad appear to be genetically dependent on a granite intrusion, and thus show a mode of origin similar to the Argentine deposits rather than to the geologically recent tungsten-bearing veins of Bolivia.

The northern oil field of Peru is at present the most productive of the continent. The oil-bearing beds are of Eocene age and occur at horizons of from 250 to 1,750 feet depth in the Zorritos field and 1,500 to 3,200 in the Lobitos. In the Negritos area the most productive horizon is at a depth of 3,900 feet.

Coal is found at many places in Peru, but except for production by the Cerro de Pasco Company for its own use, lack of transportation has prevented development.

Uruguay has no mineral production of importance, but deposits of manganese and iron offer prospects for future development.

The El Callao gold mine in Venezuela was formerly one of the famous mines of the world and is beliveed to have produced nearly 1,500,000 ounces of gold from quartz vein associated with diabase. The iron deposits of the lower Orinoco while not productive at present appear to contain considerable reserves of good ore. Asphalt is produced in several localities of which the most important is the Bermudez pitch lake. Petroleum is known in many places, but although many examinations have been made by geologists for various companies, information up to the present has been withheld. The productive strata appear to range in age from Lower Cretaceous to Miocene.

The book represents the sum of our knowledge of South American mineral deposits at the time of its publication. Naturally many productive and important districts could not be described in as much detail as their importance warrants. Geologists will be glad to get

the data here presented and will be grateful for the painstaking work which has made the book possible. In addition to the information given, the gaps in our knowledge, as brought out by this publication, are of interest. Very little is known regarding the Argentine, Colombians and Venezuelan oil fields, the bauxite deposits of the Guianas, and the platinum placers of Colombia, yet all these promise to be of considerable importance. Lack of information prevents adequate treatment of such important copper deposits as Braden and Potrerillos.

The illustrations are well selected and assist the reader greatly. It is a pity that more were not included, particularly sketch maps of the different districts, and sketches illustrating ore occurrence, as for instance in the Minasragra and Colquijirca districts.

The first chapter, on the economic geology of South America, suffers from too great condensation. This is the key chapter of the book and might well be greatly enlarged. The succeeding regional descriptions would be more readable if the physiography, geology and metallogeny had been presented more in detail, accompanied by a better map of the continent.

The descriptions of mining districts of the separate countries, and the general topographic and geologic descriptions as well, suffer greatly from the very inadequate maps. None of the maps show the topographic features. The different mineral products might easily have been indicated by using separate symbols for each product, but this has been done only in the map of Uruguay and the provincial maps of Chile. The scale has been omitted from the map of Dutch Guiana. The two worst maps are those of Argentine and Chile. A very strange effect has been produced in the former by omitting all coast lines beyond the boundaries of the country. The map of Chile shows only the provincial boundaries and, presumably to save paper, is set diagonally across the page. In the Chilean chapter, however, the inadequate map of the country is supplemented by provincial maps, which show the location of the mineral deposits. These are apparently derived from Chile Económico, published by the Oficina Central de Estadística.

South American mining districts have developed their own terminology and it is difficult to avoid the excessive use of local terms, which are expressive in their own habitat and are difficult to translate exactly into English. The authors have endeavored to avoid Spanish terms where English equivalents are available. A few words and phrases, however, such as *altaplanicie* and *capas esmeraldíferas* might better have been given in English.

Great care has been taken in reproducing the Spanish accents on geographical names. The only exception noted, the omission of the

accent from Potosí, will give further currency to a common mispronunciation.

A résumé of mineral production heads each of the chapters on the different countries. For many South American countries there are no reliable data as to exports or production, but annual statistics are published for Peru, Bolivia and Chile and it might have been of interest wherever possible to give a summary of mineral production in tabular form. In the discussion of Bolivian production the authors have confused exports of ore with production of metal. Metric and English tons are not always distinguished.

Each chapter is followed by a "selected bibliography" on the mineral deposits of each country. Those under Chile and Peru each exceed 200 titles. Brief descriptive notes by the authors add greatly to the value of the references. It might have been helpful, however, if selection had been carried out rather more rigorously or if the authors had indicated in some way the most important papers in each bibliography. Much of what has been written on Spanish-American geology and mineral deposits is nearly worthless, and since the authors have been at pains to go through the mass of material they could have saved others much labor either by excluding the poorest or by indicating the best. The value of the bibliographies might also have been greatly increased by giving more references to them in the text, particularly as regards minor minerals. For instance, the specialist in search of further information on iron in Argentina, cobalt in Chile, antimony in Bolivia and Peru and many minor but productive deposits is obliged to search through the bibliography for titles apparently bearing on his subject. The references have been entirely omitted from the chapters on Uruguay and Venezuela.

Most of the chapters include a section on conditions governing and affecting the mining industry, which contains information of value and might advantageously be expanded by information as to living conditions, costs, mining laws, etc.; in general such information as no doubt the authors have been many times requested to supply orally.

The book is of such great and timely value, not only to geologists and mining engineers but to all interested in the development of South American resources, that it is to be hoped that a second edition will soon be required. This will give the authors opportunity to include new material published by others since the book was written, and also the results of the more detailed study of the Bolivian deposits now being undertaken by Dr. Singewald.

HENRY G. FERGUSON.

SCIENTIFIC NOTES AND NEWS[1]

ADOLPH KNOPF, of the U. S. Geological Survey, has been inspecting the Divide district of Nevada.

DR. JOSEPH E. POGUE, formerly Associate Professor of Geology and Mineralogy in Northwestern University, has terminated his duties as Assisting Director in Technical Matter, Bureau of Oil Conservation, Oil Division, U. S. Fuel Administration, and accepted the appointment of Curator in the Division of Mineral Technology, U. S. National Museum, where he will carry on educational and investigational work in industrial economics with special reference to mineral industries.

J. E. SPURR has resigned as Executive of War Minerals Investigations, Bureau of Mines, and has accepted the position as editor of the *Engineering and Mining Journal.*

EDSON S. BASTIN, who is in charge of the mineral resources division of the U. S. Geological Survey, has accepted an appointment to the chair of economic geology in the University of Chicago. He will continue his work with the survey until January 1, after which he will enter upon his new duties.

VICTOR C. HEIKES, of the U. S. Geological Survey, has returned to his headquarters at Salt Lake City, after making a tour of the mining camps of Arizona.

SCOTT TURNER has been appointed consulting engineer of the Mining Corporation of Canada, Ltd., with offices at the Bank of Hamilton Building, Toronto, Canada.

J. F. KEMP has gone to Cornucopia, Oregon.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

FRANK D. ADAMS, dean of the faculty of applied science at McGill University, Montreal, has been appointed acting principal of the university during the absence of Sir Auckland Geddes, who has been given a year's leave.

RALPH ARNOLD has completed his government service and resumed practice as consulting petroleum geologist and engineer with offices in Los Angeles and New York.

A. G. BURROWS AND PERCY HOPKINS, of the Ontario Bureau of Mines, are making an examination of the Boston Creek gold district, a detailed map of which will be issued.

OSCAR G. HERSHEY, geologist for the Tom Reed Gold Mines Co., recently visited that company's property at Oatman.

ROBERT HARVIE AND EUGENE POINTIN, of the Department of Mines, Ottawa, are continuing their investigations of the serpentine belt in the Thetford district.

A. G. BURROWS AND CYRIL KNIGHT, of the Ontario Bureau of Mines, are making geological surveys for a map embracing the Kirkland Lake, Boston Creek, Larder Lake, and Skead Township gold areas.

J. A. BURGESS, of Oatman, Ariz., until recently superintendent of the United Eastern Mining Co., has been promoted to the position of general manager, with headquarters at the same place.

W. O. HOTCHKISS, State Geologist of Wisconsin, has a large field party doing detail geology on the western end of the Gogebic Range.

E. L. PORCH, JR., has been discharged from the army and has opened an office as petroleum geologist and mining engineer in the Alamo National Bank Bldg., at San Antonio, Tex.

VAN H. MANNING, Director of the U. S. Bureau of Mines, received the honorary degree of doctor of engineering from the University of Pittsburgh at the Commencement on June 21.

JOHN E. PENBERTHY, superintendent of the Shannon Copper Co. interests at Gleeson, Ariz., has returned from a trip of mine examinations in New Mexico.

WALTER DOUGLAS, President of the Phelps Dodge Corporation, of New York, has completed a tour of inspection of the various Phelps Dodge properties in Arizona, New Mexico, and Sonora, Mexico.

WILLIAM W. MEIN is at Lake Tahoe.

GEORGE A. MACREADY, for several years resident geologist for the Trinidad Lake Petroleum Co., at Trinidad, B. W. I., is now located at Los Angeles, Calif.

A. CHESTER BEATTY has given up his residence in England and is returning to the United States. His business address will be 25 Broad St., New York City.

CHESTER A. HAMMILL has resigned from the geological department of the Roxana Petroleum Co. He will undertake independent investigations with headquarters at 1417 American Exchange Bank Bldg., Dallas, Tex.

JOHN T. REID, mining engineer, of Lovelock, Nevada, who has just completed extended examinations of mining properties in northeastern Oregon, is about to leave Nevada for New York where he will remain for some time.

MELVIN BRUGGER has accepted a position as mining geologist and engineer for the Minas de Matahambres Mining Co., operating copper and silver properties in Cuba.

JAMES S. DOUGLAS, president, United Verde Extension Mining Co., has returned to Douglas, Arizona, from a trip of inspection of the Verde X mine and smelteries at Jerome.

CHARLES WILL WRIGHT has arrived at Sault Ste. Marie, Michigan, from Igurtoso, Sardinia, where he has been managing lead-zinc mines. He will return to Sardinia in September.

MESSRS. B. S. BUTLER AND F. C. CALKINS, of the U. S. Geological Survey, are at work in the Cottonwood district, Utah.

MR. H. G. FERGUSON, of the U. S. Geological Survey, is revisiting Manhattan, Nevada, in order to complete his report on that district.

MESSRS. E. R. LLOYD AND D. E. WINCHESTER have resigned from the U. S. Geological Survey to engage in private work in the geology of oil. Mr. Lloyd will be with the Sinclair Co. at Caspar, Wyo.

L. D. RICKETTS, of Warren, Ariz., who, during the absence of Col. John C. Greenway in France, has had charge of the management of the Calumet and Arizona properties in Arizona, is at present visiting the East. During the summer Dr. Ricketts will spend a part of his time with his family at Santa Barbara, Calif., at the El Marisol Hotel.

MARK L. REQUA, general director of the oil division of the U. S. Fuel Administration during the war, has resigned from that post and become associated with the Sinclair petroleum interests.

PROF. L. G. WESTGATE, of Ohio State University and the U. S. Geological Survey, is in Palestine, engaged in geological investigations for the Zionist Organization. He expects to remain there until November.

MR. J. B. UMPLEBY has resigned from the U. S. Geological Survey to take the chair of geology at the University of Oklahoma.

A REPORT on the geology of the copper deposits of the Ray and Miami districts, Arizona, by F. L. Ransome, is in press as Professional Paper 115 of the U. S. Geological Survey. It should be available for distribution late in September or early in October.

MR. H. D. MCCASKEY, although retaining a connection with the U. S. Geological Survey, has retired from active duty with that organization and will engage in apple growing in the Rogue River Valley, Oregon.

MESSRS. ROBERT H. WOOD AND VIRGIL O. WOOD, late of the United States Geological Survey and the Ohio Oil Co., respectively, announce the formation of the firm Wood and Wood, for the practice of general petroleum geology, with offices at 516–517 New Daniels Bldg., Tulsa, Okla.

N. H. DARTON, U. S. Geological Survey, has completed a report on structure of New Mexico with special reference to oil and gas prospects. He will spend September in the field completing a geologic map of the State.

IN OCTOBER reconnaissance will be extended into eastern central Arizona for a geologic map of that State in coöperation with the State Geological Survey.

T. WAYLAND VAUGHAN, D. DALE CONDIT, C. Wythe Cooke and Clyde P. Ross, of the U. S. Geological Survey, have recently returned to Washington after spending several months in a reconnaissance of the Dominican Republic, for the Dominican Government. Dr. Vaughan also visited Prince au Prince, Haiti, and made arrangements with the Haitian Government for a preliminary geological survey of Haiti. He later made a reconnaissance in the Virgin Islands at the request of the Navy Department. Mr. Condit, who was in charge of the field work in Santo Domingo, has in preparation several reports one of which, soon to be published, will describe the results of geologic work in Barahona and Azua Provinces.

LIEUTENANT COLONEL GLENN SMITH, who was recently in Santo Domingo in order to make arrangements for a topographic survey of the Dominican Republic, has taken to that country a party of twenty topographers of the U. S. Geological Survey who will at once begin mapping. Plans for similar work are also being made for Haiti and other parts of the West Indies. Lieutenant Colonel Smith has recently been appointed chief of the Division of West Indian Surveys, a new branch of the U. S. Geological Survey.

THROUGH the action of the congressional Public Buildings Commission, of which Senator Smoot is chairman, the U. S. Geological Survey has been compelled to give up to the Internal Revenue Bureau nearly half of its office space in the Interior Department Building. This by forcing as many as three geologists to work in a single small room with no adequate space for the study of maps and collections is a serious blow at the efficiency of the organization. The action is an example of the failure of Congress to understand the nature of scientific work and to realize that a geologist's room is essentially a laboratory within which it should be possible to retain in accessible condition, collections of minerals, rocks and ores representing field work that in some investigations may extend over a period of several years.

ERRATUM. No. 4, June number, 1919: In the paper "Notes on the Placer Mines of British Columbia," by J. B. Tyrrell, p. 340, on Plate X., the title for Fig. *a* should be transposed with that of Fig. *c*.